RSES

Air Conditioning and Heat Pumps

PREPARING FOR THE NATE EXAM

Human Comfort and System Selection

Chapter 1

Lesson Objectives

- Comfort – All Measures.
- Factors in System Selection.
- Ventilation.

The Goal of Air Conditioning - Comfort

- The ideal indoor environment:
  - Temperature.
  - Humidity.
  - Circulation.
  - Filtration.

Factors in Choosing a Mechanical System

- Type of building.
- Quality of construction.
- Commercial or residential.

Building Construction

- Building materials and insulation reduce thermal transmission:
  - Less heat loss through building surfaces.
  - Reduced temperature difference between wall surface and inside air temperature reduces radiant heat gain/loss from the body.

Building Construction

- Tighter building construction reduces air infiltration from the outside:
  – Tighter windows and doors; and
  – Sealed penetrations and cracks.
- Effects temperature and relative humidity.

Building Construction

- Shading affects solar heat gains:
  - Overhangs;
  - Trees;
  - Hills;
  - Other buildings; and
  - Orientation:
    - North, south, east or west.

Moisture Control

- Achieved through vapor barriers:
  - Retards moisture migration; and
  - Prevents building damage.
- Added inside the home:
  - Humidifiers, dishwashers, etc.
- Proper relative humidity (RH) is critical for:
  - Comfort and health of occupants; and
  - Furnishings and wood trim.

Air Filtration

- A complete comfort system cleans and filters the air.
- Clean air is as important as proper temperature and humidity.

Design Tools

- ACCA Manual J: Residential Load Calculation;
- ACCA Manual N: Commercial Load Calculation;
- ACCA Manual D: Residential Duct Design; and
- ACCA Manual Q: Commercial Duct Design.

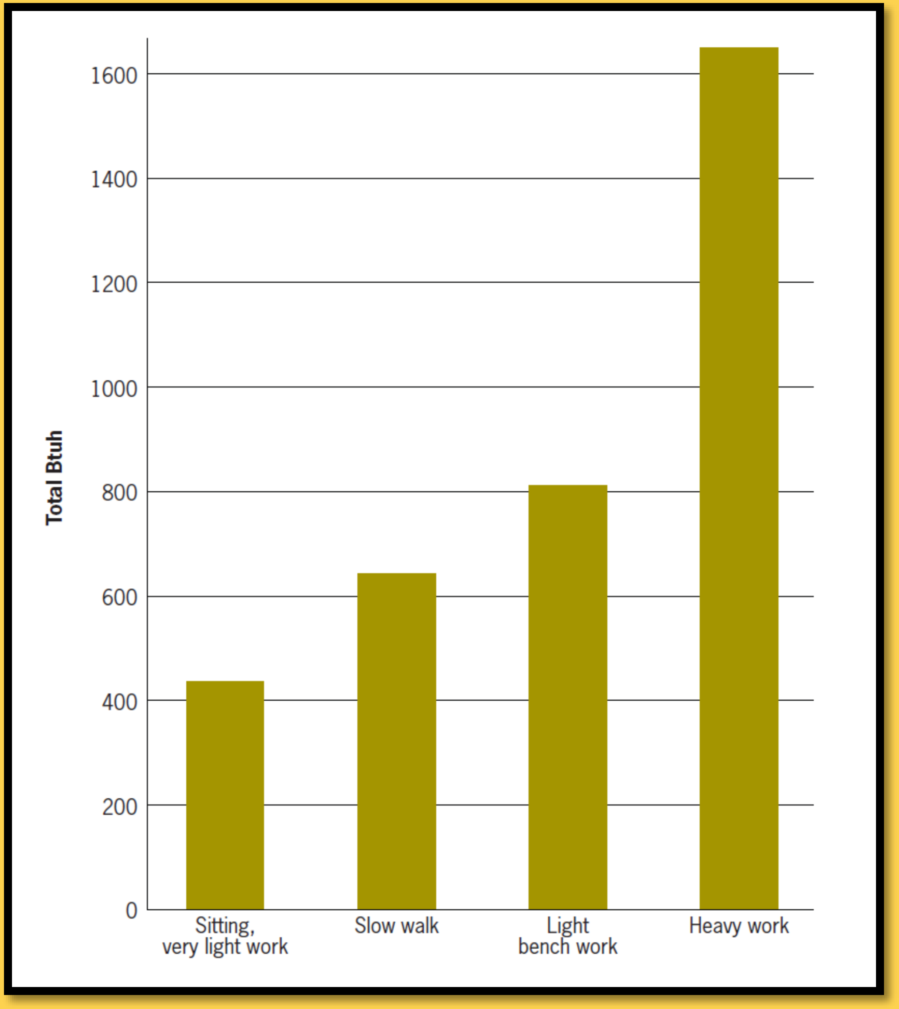
What Makes People Comfortable?

- Temperature;
- Humidity ;
- Air movement;
- Air cleanliness; and
- Fresh air ventilation.

Air Changes

- 0.3– 0.5 air changes per hour recommended.
- ERVs (Energy Recovery Ventilators) can assist this process while exchanging temperature and humidity between airstreams.

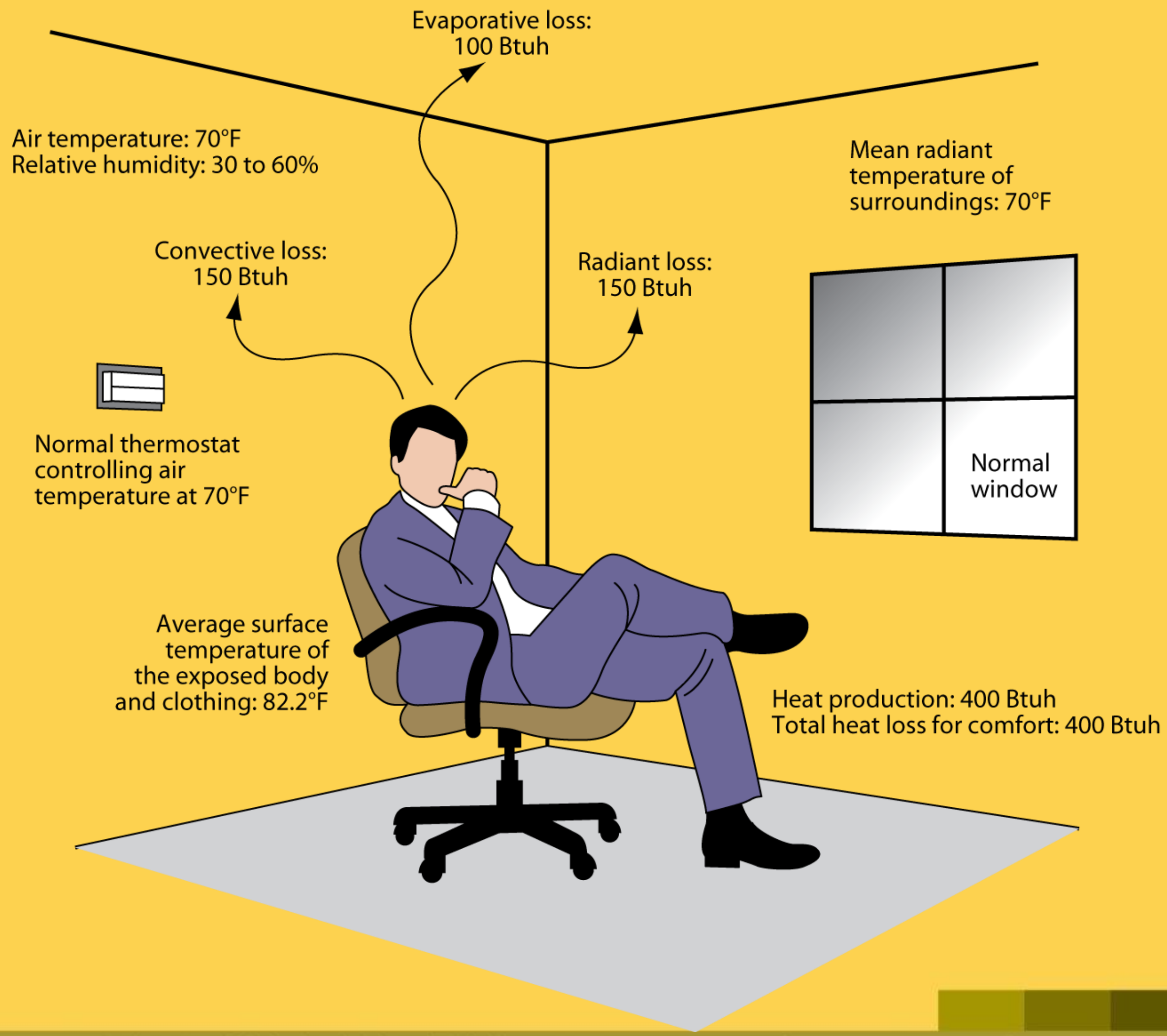
Heat Generated by Physical Activity



Temperature

- People generate heat at different rates depending on activity.
- People give up heat by:
  – Radiation;
  – Convection; and
  – Evaporation.
- Surface temperatures affect the amount of radiation absorbed or rejected by the body.

Convection, Evaporative, and Radiant Body Heat Losses



Thermal Envelope

- Major factor in providing comfort.
- Insulation can reduce radiant heat loss.
- Wall surface temperatures are just as important as room air temperature to occupant comfort.
- Vertical temperature difference from 4 in. to 67 in. should not exceed 5°F.

Humidity

- Humidity effects comfort by affecting the rate of evaporation from the body.
- Humidity also effects the body's health:
  - Static electricity is a problem in very low humidity;
  - Flu viruses flourish in low humidity;
  - Dust mites flourish in higher humidity; and
  - Molds grow in high humidity.

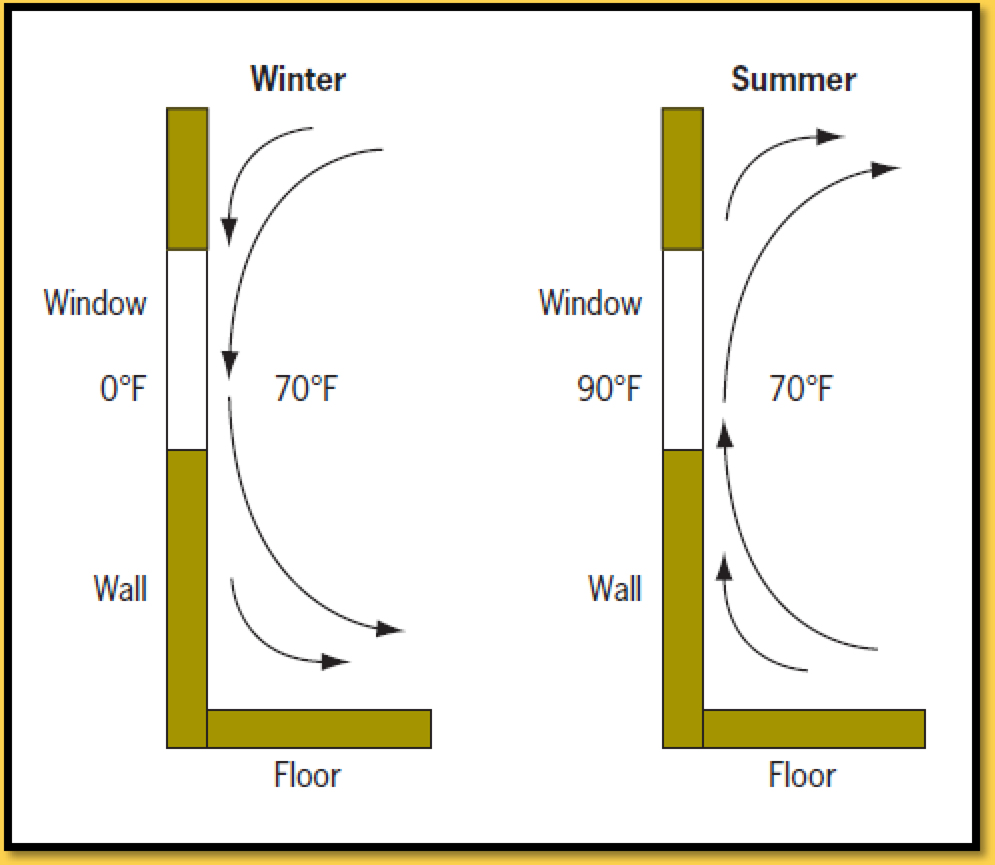
Air Movement

- Air movement can make a person feel cooler.
- Air movement is important to prevent stratification or temperature gradients.
- Excessive air movement in the “occupied zone” will feel drafty and uncomfortable.

Velocity	Result
15 ft/min	Cigarette smoke hangs in the air
65 ft/min	Paper blows off a desk
160 ft/min	Hair and light objects blow about

Natural Convection

- Warmer air rising and cooler air falling.
- Mechanical ventilation or forced convection.



Forced Convection

- Mechanical equipment creates forced convection to interrupt natural convection and de-stratify the room air, thus improving comfort.
- Air movement within the occupied zone of a room should be maintained at an average velocity of 30 ft/min in winter and 50 ft/min in summer.

Occupied Zone

- The occupied zone of a room extends from the floor up to 6 ft above the floor, and to within 2 ft of the room's walls:
  - The adjusted dry-bulb temperature within this zone should range from 67°F–73°F in winter and from 73°F–79°F in summer; and
  - For industrial ventilation applications, the adjusted dry-bulb temperature may be increased 1°F for every 30-ft/min increase in average air motion up to 160 ft/min.

Ventilation

- The exchange of outside air is required to provide oxygen and remove contaminates.
- Older buildings used natural ventilation:
  - Leakage of the structure and windows.
- Newer structures use mechanical ventilation:
  - Energy recovery ventilators;
  - Air intakes; and
  - Exhaust fans.

Equipment Selection

- Equipment selected should match the calculated heat gain or loss as close at possible:
  - Cooling equipment not more than 15% greater than the sensible heat gain.
    - Heat pumps up to 25% with larger heating loads.
  - Cooling equipment equal to or greater than the latent heat load.

Equipment Selection

- Heating:
  - Heat pump plus auxiliary heat should not exceed 15% of the total load; and
  - Fossil-fuel equipment should be the next size larger than the load.

System Capacity

- System capacity is effected by outside factors:
  - Outside temperatures;
  - Water temps on water-source heat pumps; and
  - Dry-bulb and wet-bulb temperatures entering the evaporator:
    - The amount of ventilation air added will effect these readings, as illustrated on the next slide.

Outdoor dry-bulb temperature (°F)	Indoor wet-bulb temperature (°F)	Total capacity (Btuh x 1000)	Sensible capacity (Btuh x 1000) at entering dry-bulb temperature (°F)			
			72	75	78	80
85	59	22.4	20.2	22.5*	23.5*	24.1*
	63	24.3	16.8	19.4	22.1	23.8
	67	26.3	13.1	15.7	18.4	20.1
95	59	20.9	19.5	21.3*	22.3*	22.8*
	63	22.7	16.1	18.8	21.4	22.8*
	67	24.6	12.5	15.1	17.7	19.4

*Dry coil condition (total capacity = sensible capacity). Total capacity valid for wet coil only.

Sensible Heat Ratio

- A cooling system must be able to remove moisture as well as cool the air.
- Sensible heat ratio is the amount heat absorbed to change the temperature of the air compared to the heat absorbed to condense moisture from the air.

Thermal Balance Point

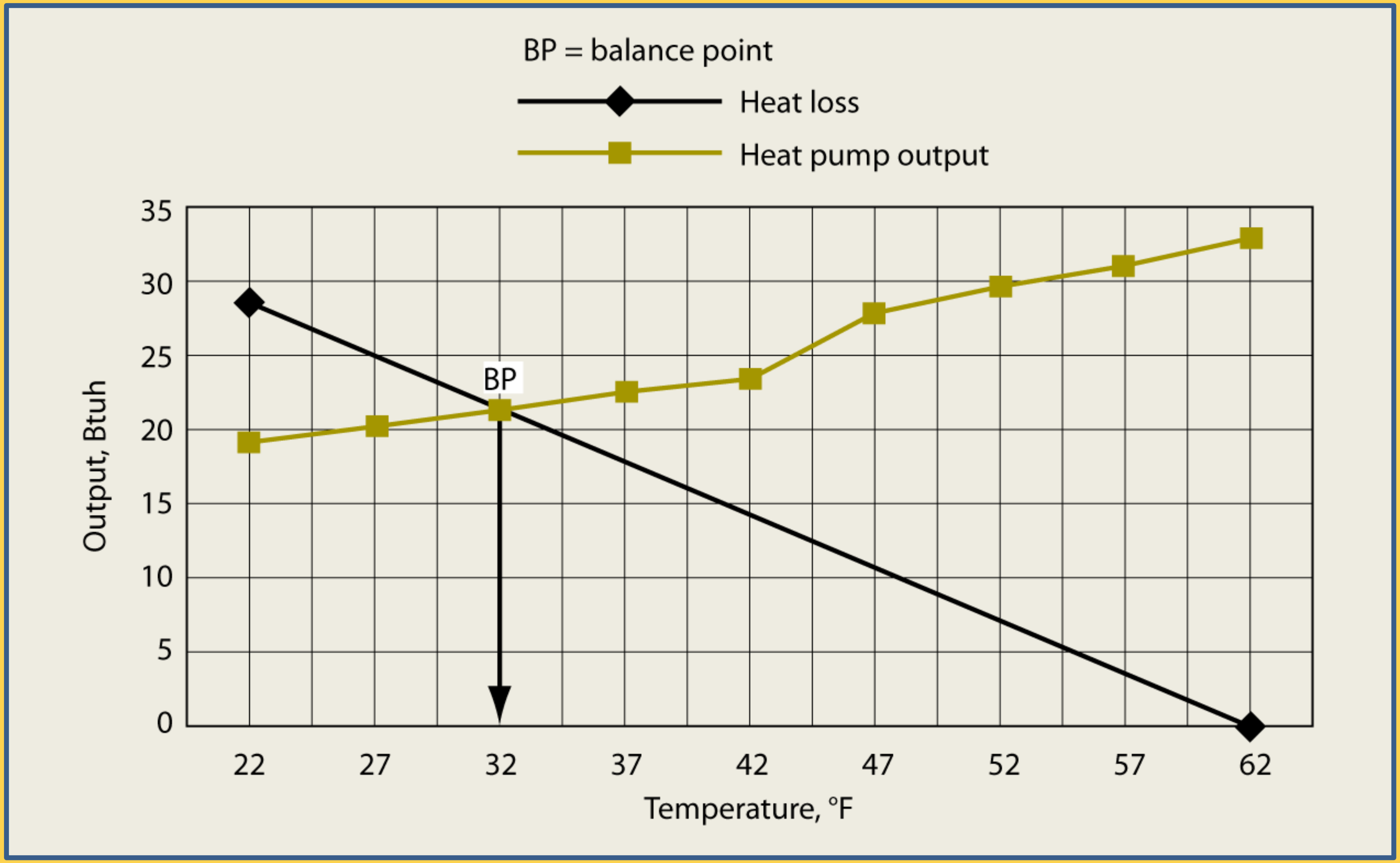
- As the outside temperature decreases the heating capacity of an air-to-air heat pump decreases.
- The point at which the load on the space matches the heat pump's capacity would be the thermal balance point.

Thermal Balance Point

- In this example: The thermal balance point occurs when the outdoor temperature is 32°F and the output of the heat pump is 21,400 Btuh.

Outdoor temperature (°F)	Heating capacity (MBh) at entering dry-bulb temperature (°F)		
	70	75	80
2	13.	13.0	13.0
7	14.7	14.7	14.6
12	16.4	16.3	16.3
17	18.0	18.0	17.9
22	19.2	19.1	19.0
27	20.3	20.2	20.1
32	21.4	21.3	21.2
37	22.5	22.4	22.3
42	23.6	23.5	23.4
47	27.9	27.8	27.7
52	29.6	29.5	29.3
57	31.2	31.1	31.0
62	32.9	32.7	32.6
67	34.5	34.4	34.2
72	36.2	36.0	35.9

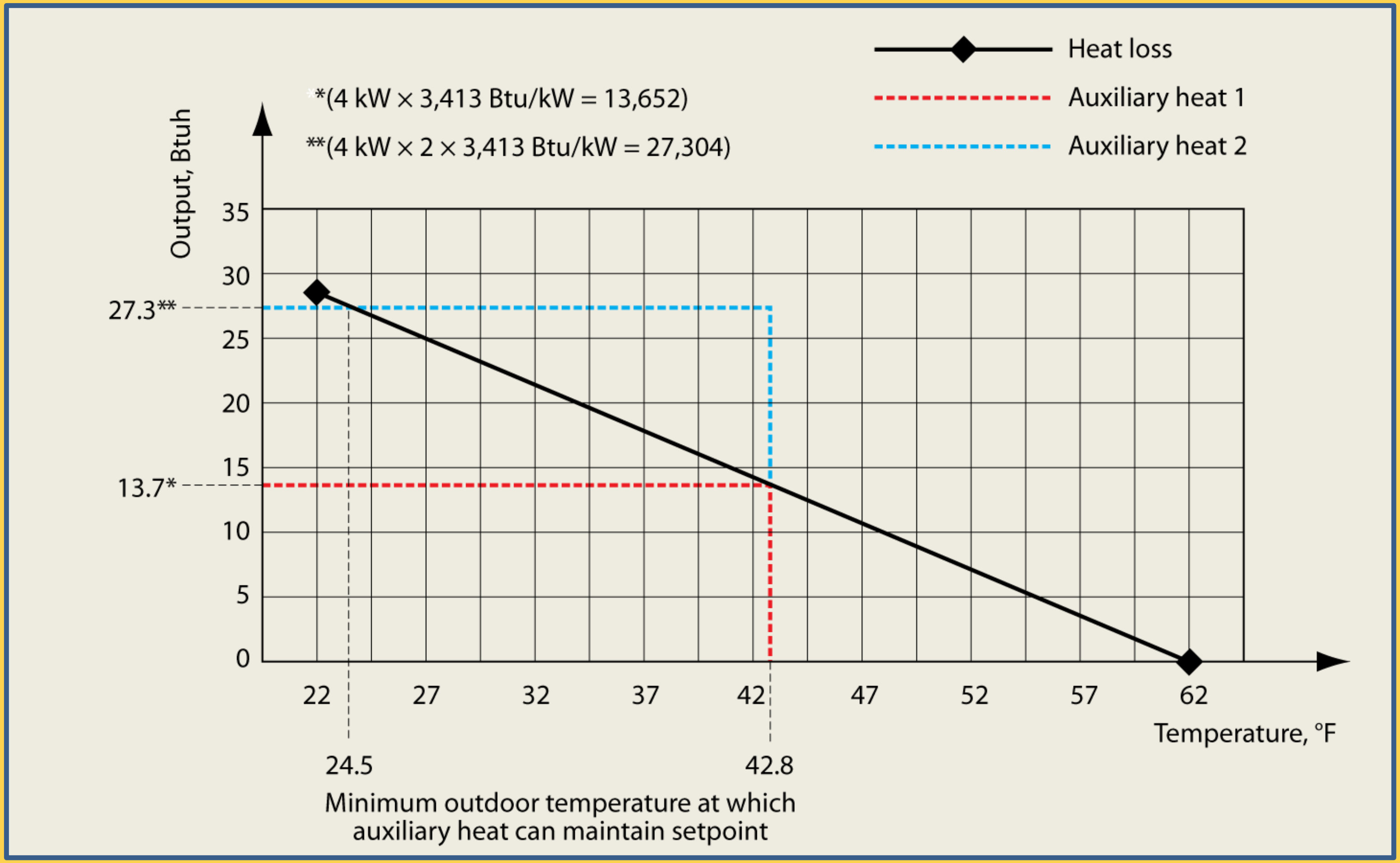
Thermal Balance Point



Economic Balance Point

- When systems use a fossil-fuel furnace for back up, an economic balance point is often used to determine when to switch from the heat pump to the fossil fuel.
- As the heat pump loses capacity it becomes less efficient and eventually it becomes cheaper to use the fossil-fuel system.

Emergency Heat



Noise Control

- Noise influences overall comfort:
  - Equipment:
    - Location ; and
    - Isolation.
  - Airflow:
    - Proper velocities.

Noise Control

- Use flexible connectors;
- Isolate ductwork;
- Use vibration isolators and pads; and
- Select proper equipment location.

Heat Transfer and the Basic Refrigeration Cycle

Chapter 2

Lesson Objectives

- Heat transfer.
- Basic theories.
- Basic refrigeration cycle.

Introduction

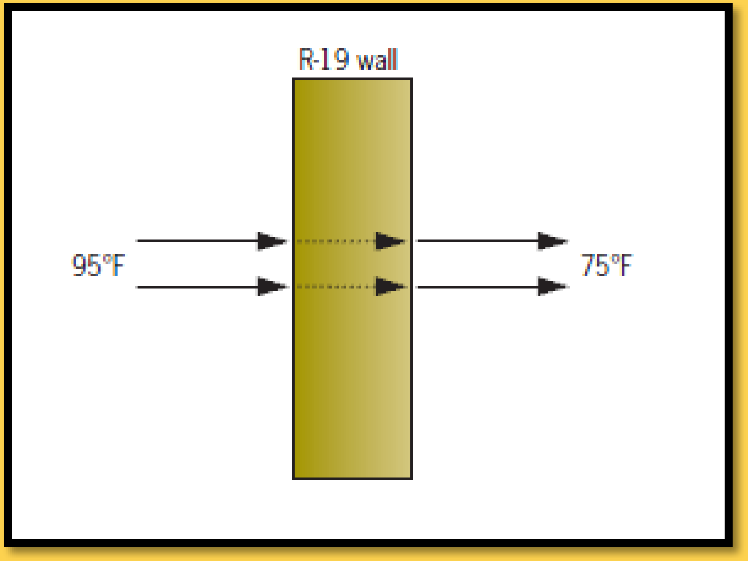
- Heat only travels from warm to cool areas.
- Blocks of ice were used historically for cooling.
- Mechanical compression was first use in 1855.
- Willis Carrier pioneered comfort cooling:
  - Residential air conditioning introduced in the 1920s.
  - Basic cycle has remained unchanged, though refrigerants have changed.

Heat Transfer

- Heat always moves from hot to cold.
  - Conduction:
    - Transfer through a solid material.
  - Convection:
    - Transfer through the flow of a fluid (liquid or vapor).
  - Radiation:
    - Transfer of heat through space without heating the space.

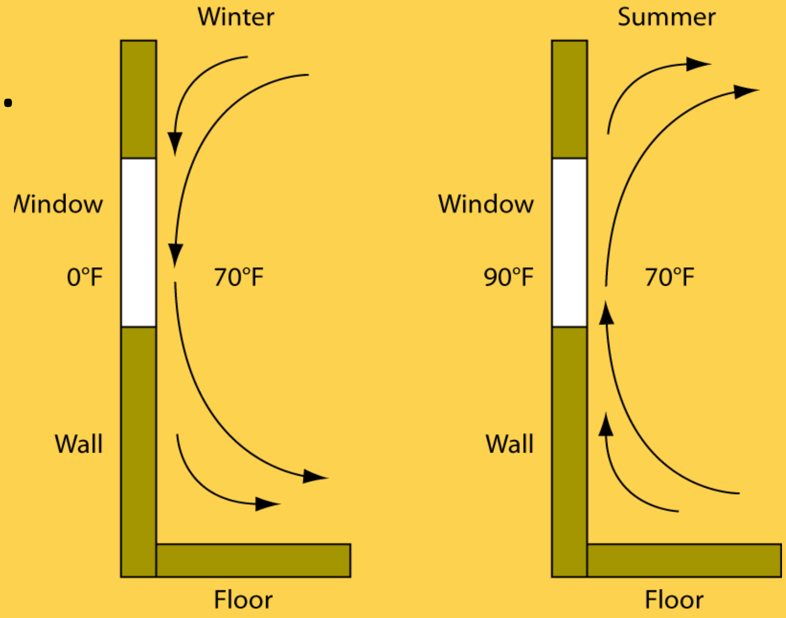
Conduction

- Transfer of heat by contact.
- Warm air to cooler indoor air through wall.



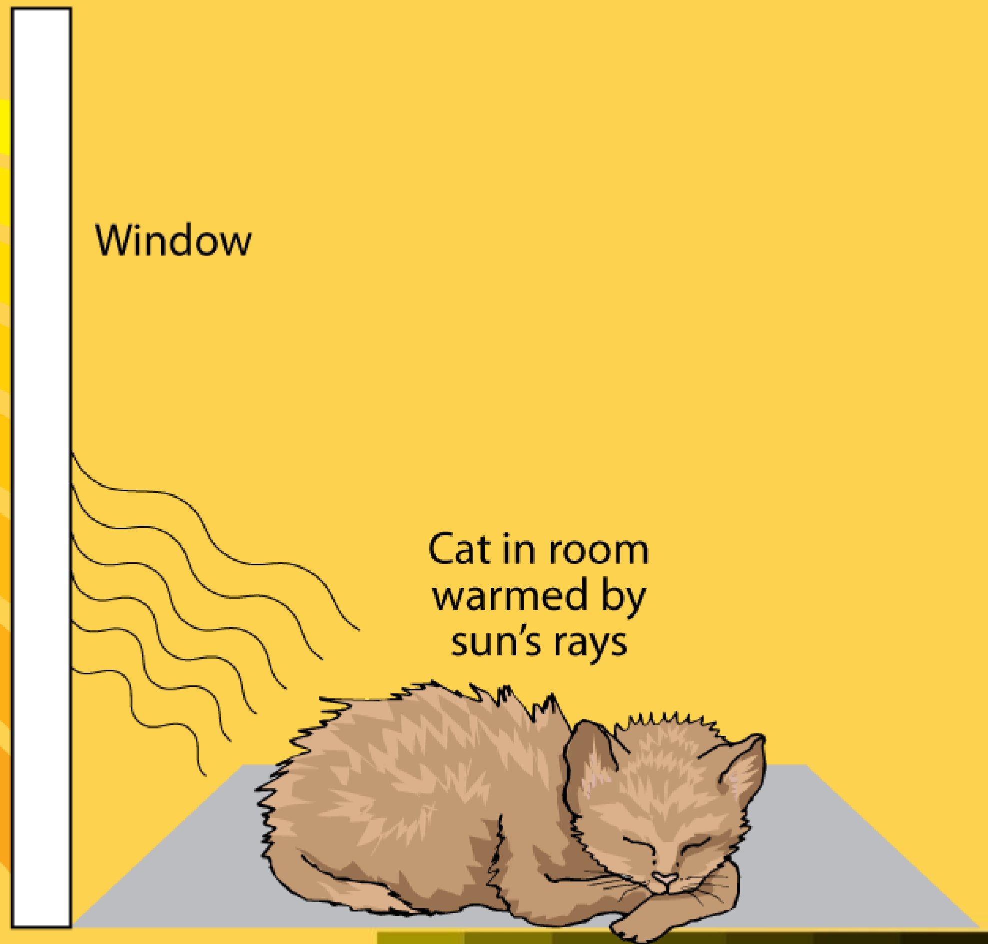
Convection

- Transfer of heat by fluid:
  - Liquid or gaseous form.
- Warm air rises.
- Cooler air falls.



Radiation

- Electromagnetic waves travel through the air.
- Temperature of the air is not changed.
- Increases temperature of objects struck.

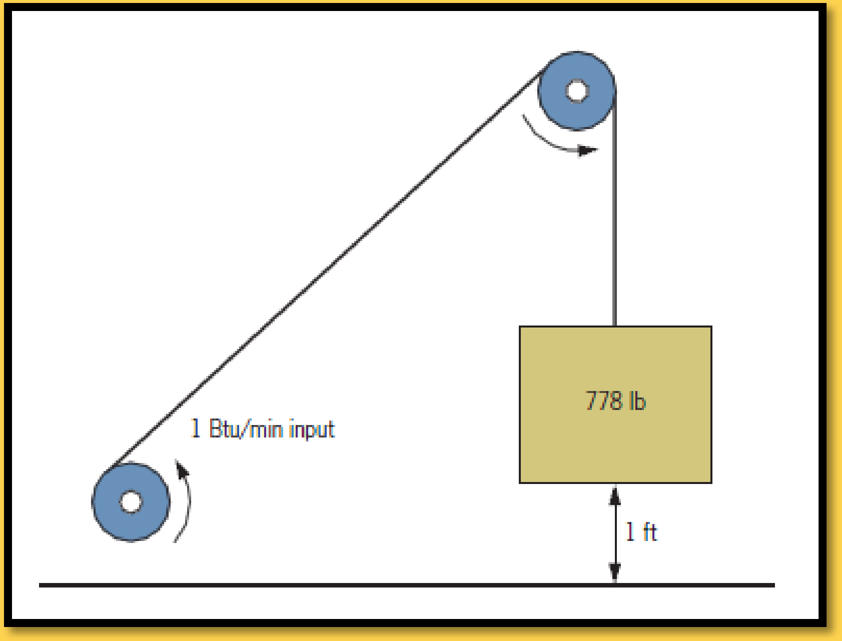


Heat

- Intensity:
  - Measured in degrees:
    - Fahrenheit;
    - Rankine;
    - Celsius; or
    - Kelvin.
- Quantity:
  - Measured in Btus.

Btu Explanation

- When converted into work energy, one Btu expended for one minute can lift an object that weighs 778 pounds one foot into the air.



Ratings

- SEER
  - Seasonal Energy Efficiency Ratio:
    - Btus per watt of energy used – average for the season.
- HSPF
  - Heating Season Performance Factor:
    - Btus per watt of energy used – average for the season.
- COP
  - Coefficient of Performance:
    - Heat output compared to electric resistance heat.
- AFUE
  - Annual Fuel Utilization Efficiency:
    - Heat output compared to fuel input.

Basic Principles

- Physical properties of liquids and gases must be understood.
- The work is not visible, but is verified by taking measurements.
- When liquids and gases change state, heat is transferred.

Basic Principles

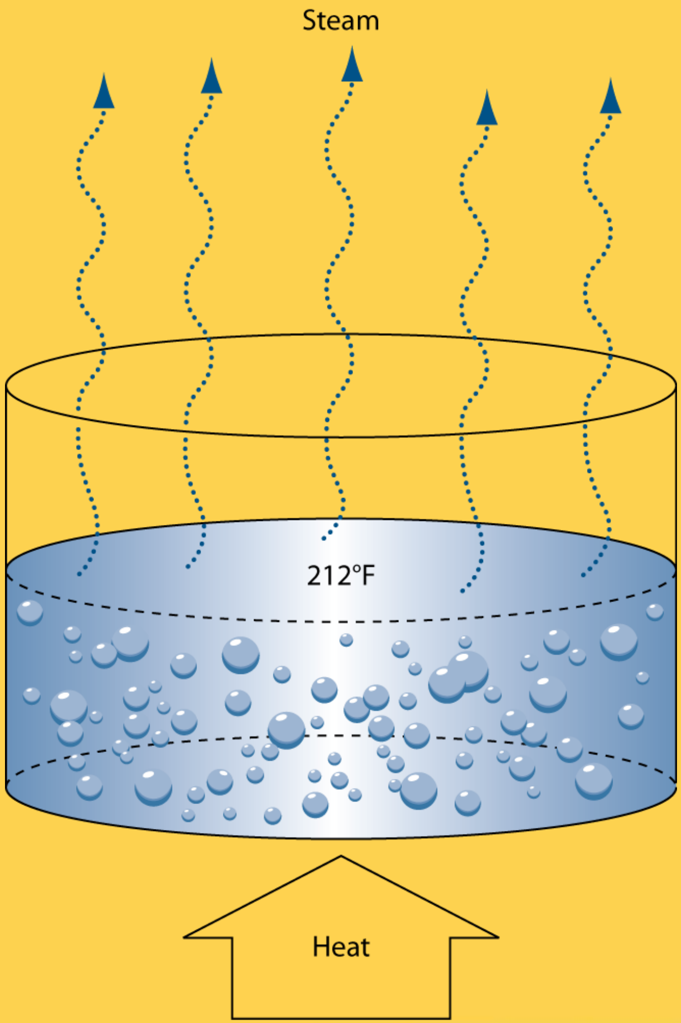
- Sensible heat:
  - Heat that when added or removed causes a change in temperature.
- Specific heat:
  - Quantity of heat required to change the temperature of 1 pound of a substance 1°F.
- Latent heat:
  - The heat required to change the state of a substance without change in temperature:
    - Requires large quantities of heat compared to heat needed to change temperature.

Basic Principles

- Latent heat of evaporation:
  - Heat required to change states from liquid to vapor.
- Latent heat of condensation:
  - Heat that must be rejected to change from a vapor to a liquid.
- Latent heat of fusion:
  - Heat that must be rejected to change from a liquid to a solid; and
  - Also the amount of heat that must be absorbed to change from a solid to a liquid.
- Latent heat of sublimation:
  - Heat absorb to change from a solid directly into a vapor.

Boiling Water

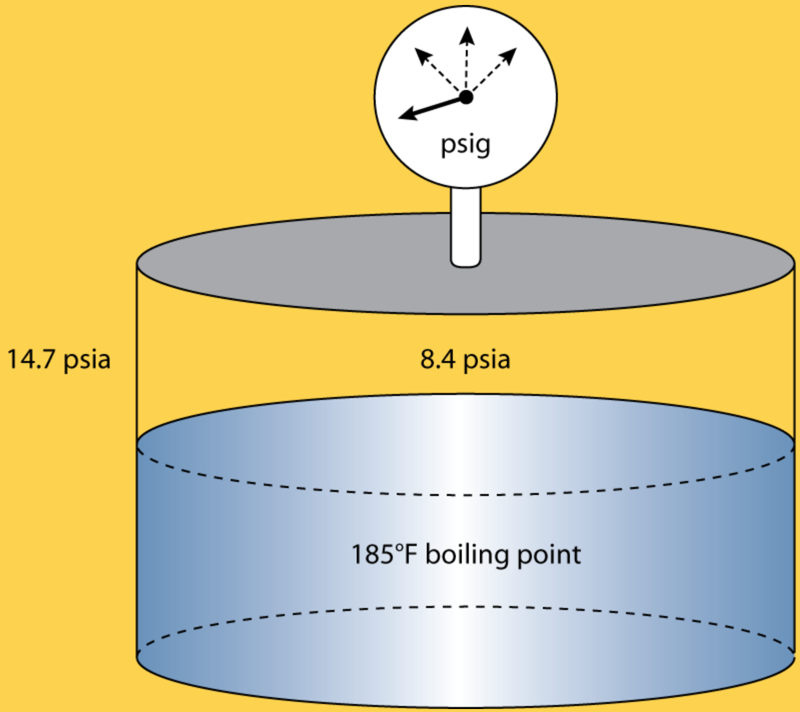
- Under atmospheric pressure (14.7 psia), water boils at 212°F.



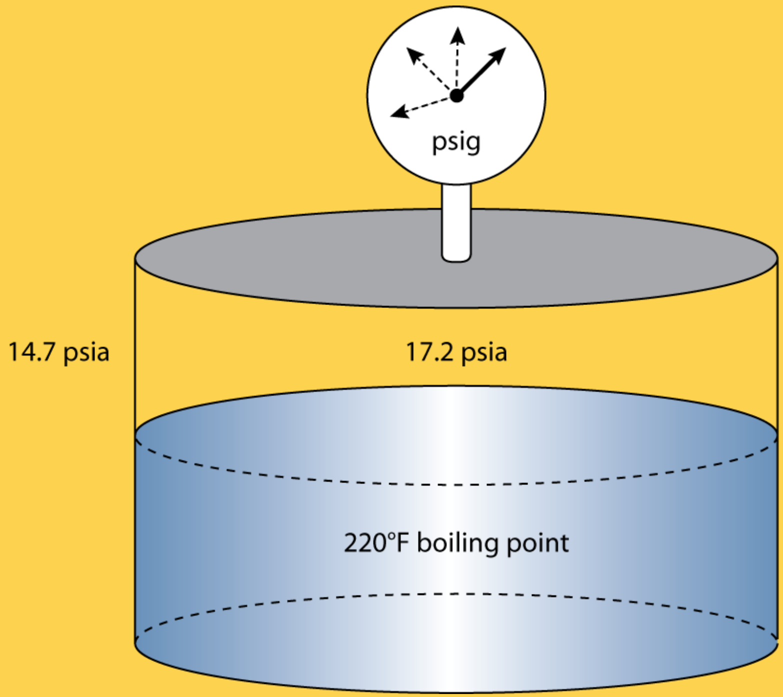
Basic Principles

- Saturation:
  - Both liquid and vapor may be present; and
  - Liquid or vapor is at the boiling temperature for the given pressure.
- Saturation temperature:
  - Dependant on pressure:
    - Increased pressure increases boiling point; and
    - Decreased pressure decreases boiling point.

Boiling and Pressure



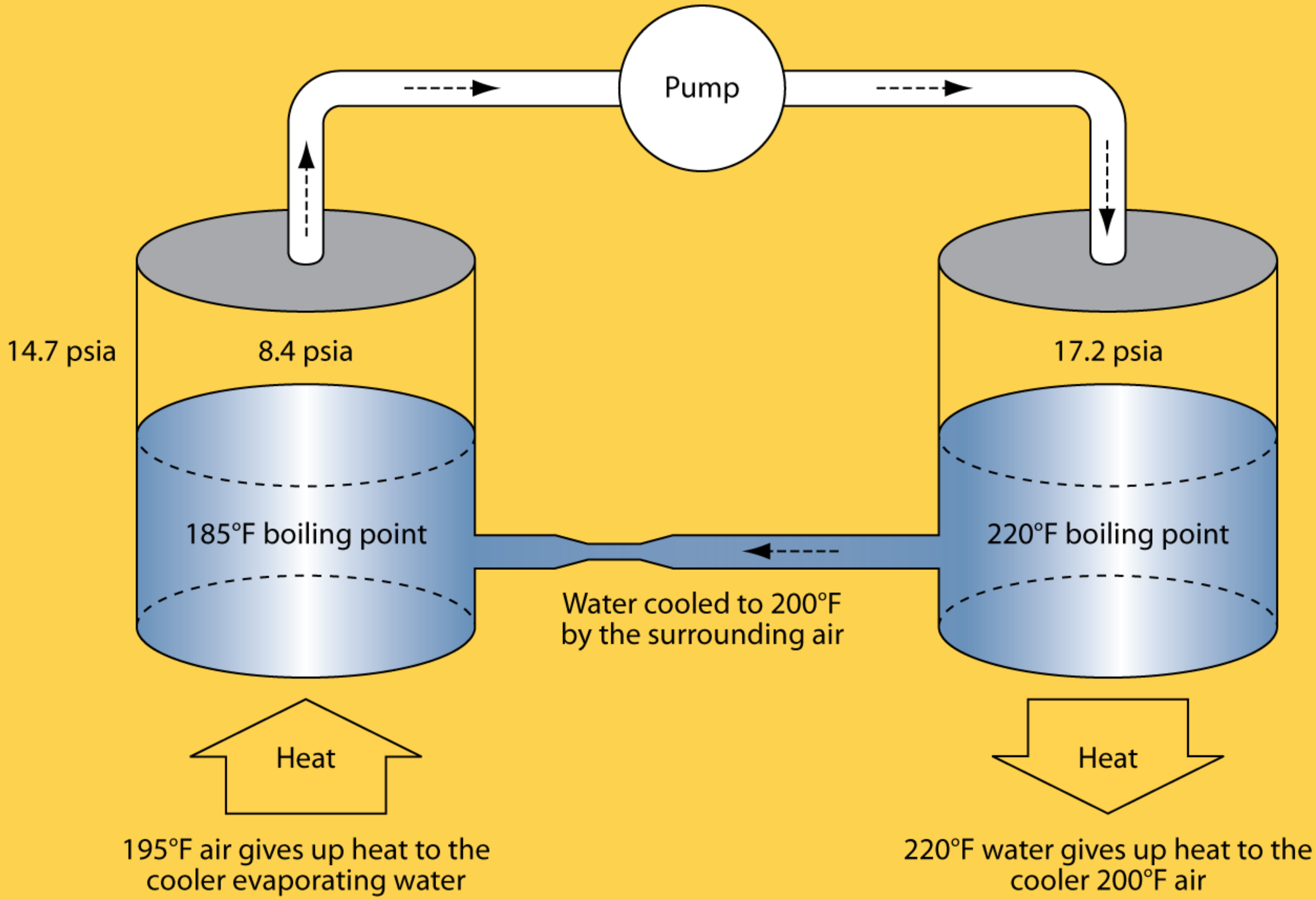
Steam and Pressure



Basic Refrigeration Cycle

- By controlling the pressure within the system we can control the temperature at which the refrigerant boils or condenses.
- The process of the refrigerant changing states absorbs or rejects large quantities of heat.

Basic Refrigeration Cycle



Fluorocarbon Refrigerants

- Sample temperature-pressure chart shown here.
- Condensing temperatures 15°F–25°F above outdoor temperature.
- Evaporating temperatures 15°F–25°F lower than air entering the evaporator.

Temperature (°F)	Pressure, psig	
	R-410A	R-22
42	122.7	71.5
45	129.8	76.1
48	137.2	80.8
105	339.6	210.8
110	364.1	226.4
120	416.9	259.9

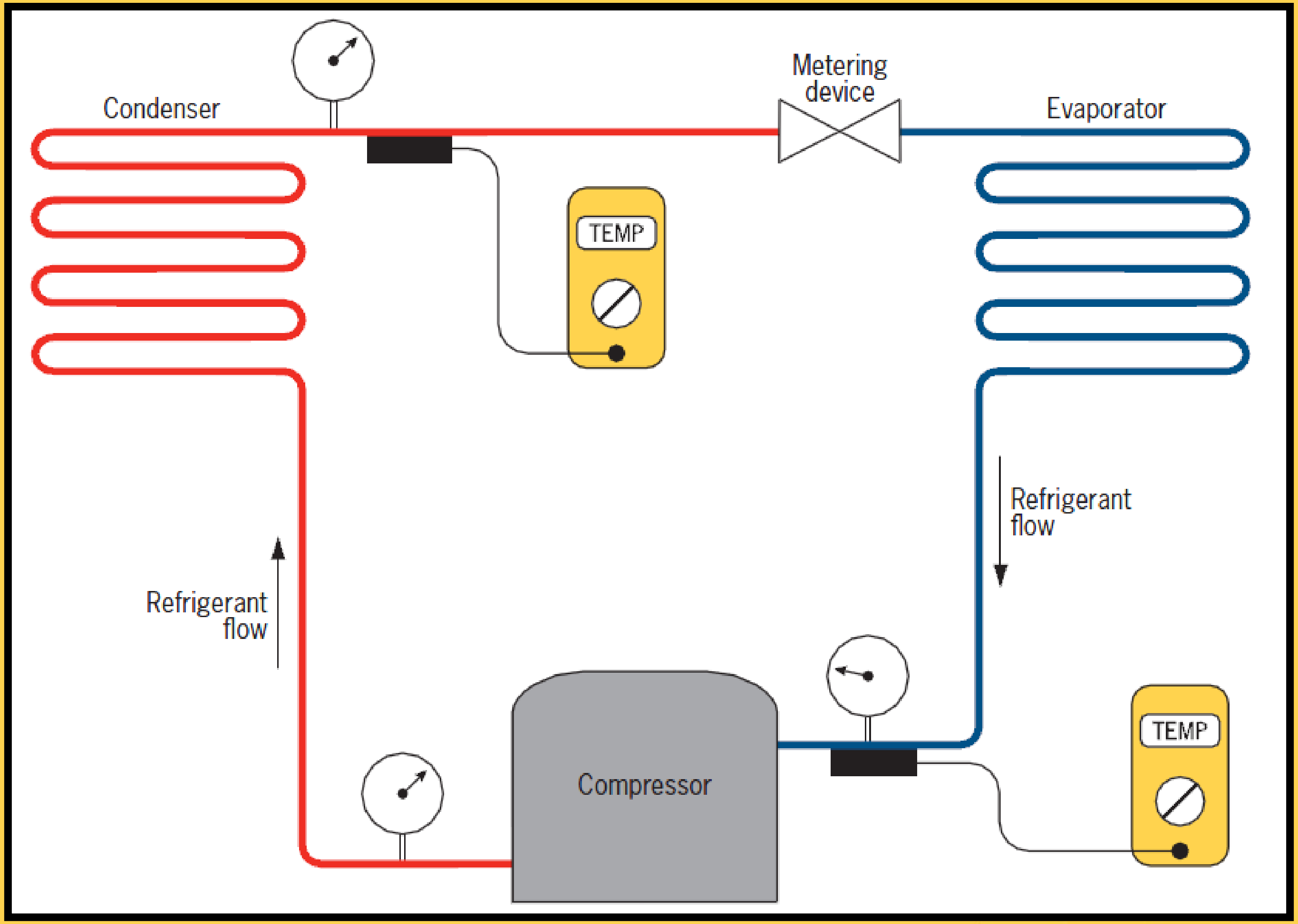
Compression Ratio

- Absolute discharge divided by absolute suction:
  - Absolute = gauge pressure + 14.7 psi (atmosphere); and
  - Cooling systems typically operate in the range of 3:1 compression ratio:
    - Heat pumps in the heating mode can be much higher.

Refrigerant Handling

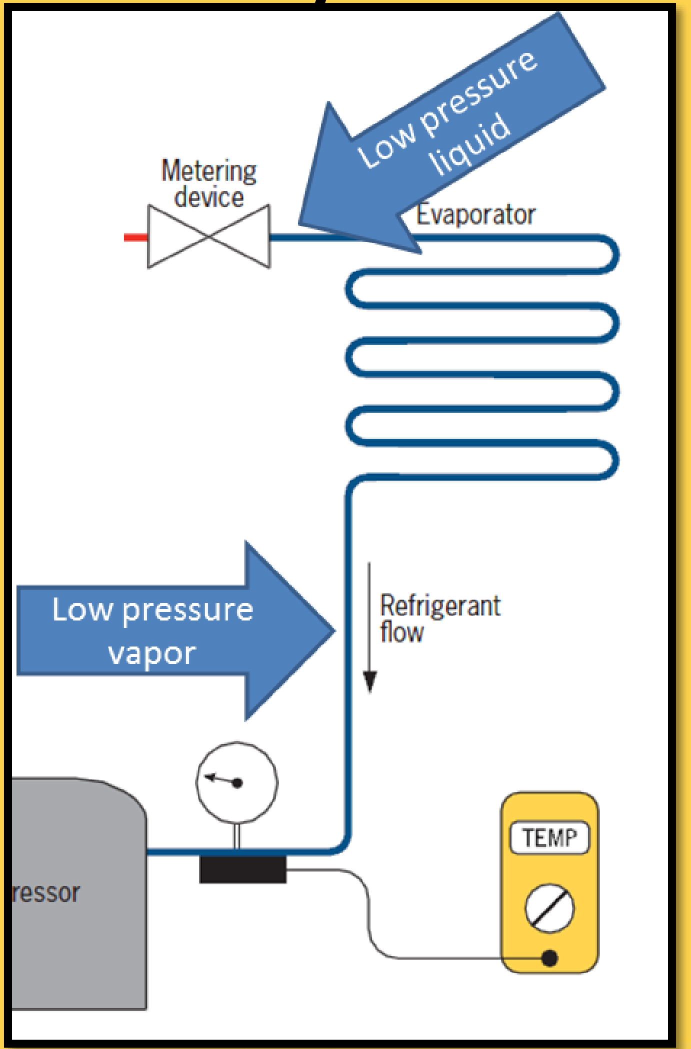
- Use proper eye and hand protection.
- Release can contribute to global warming and ozone depletion.
- Concentrations in air can cause suffocation;
  - Refrigerants are heavier than air and displace oxygen.
- Check cylinders for rust, dents or other physical damage.
- Never store cylinders above 125°F or more than 80% filled.

Basic Components Common to All Vapor-compression Systems



Basic Refrigeration Cycle

- Evaporators:
  - Typically need to operate 15 to 25 degrees cooler than the wet-bulb temperature of the air entering the coil.
  - Vapor becomes superheated.

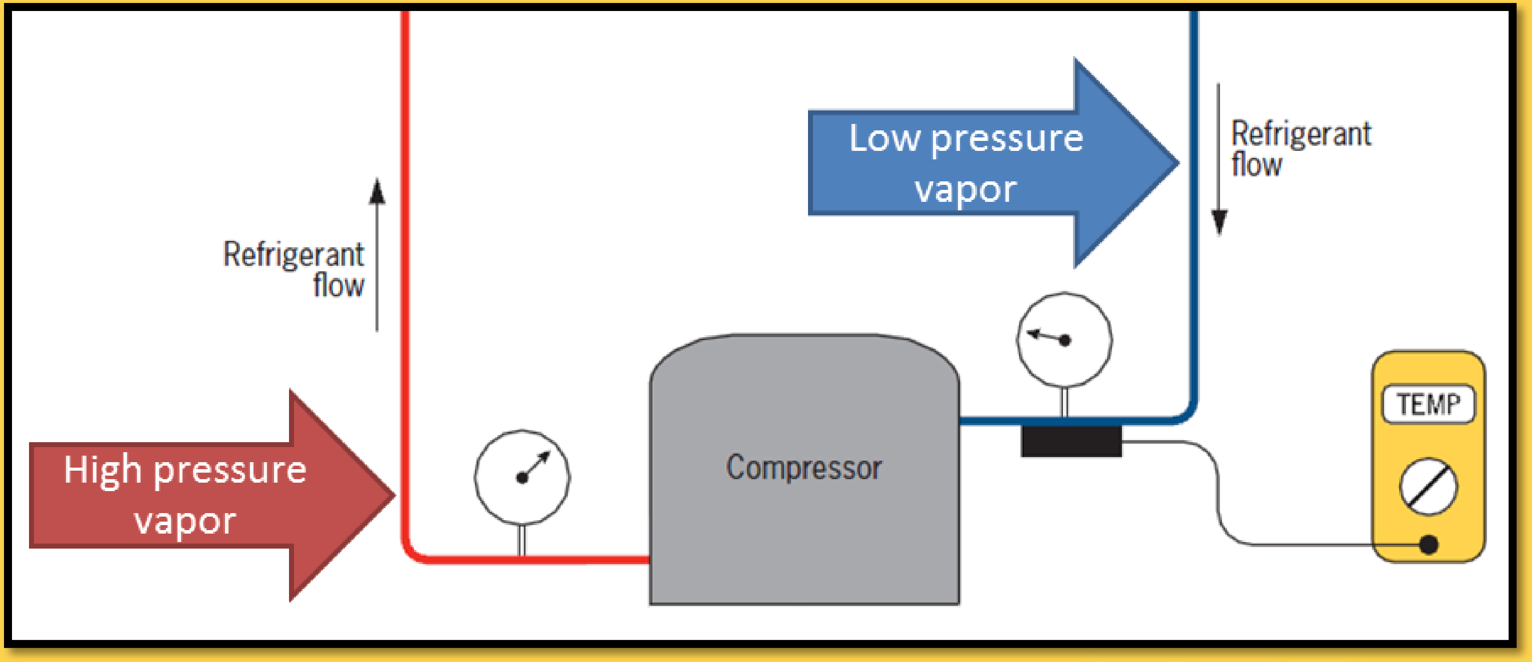


Basic Principles

- Superheat:
  - Sensible heat added to a vapor to raise its temperature beyond the saturation temperature:
    - Ensures 100 % vapor to compressor.

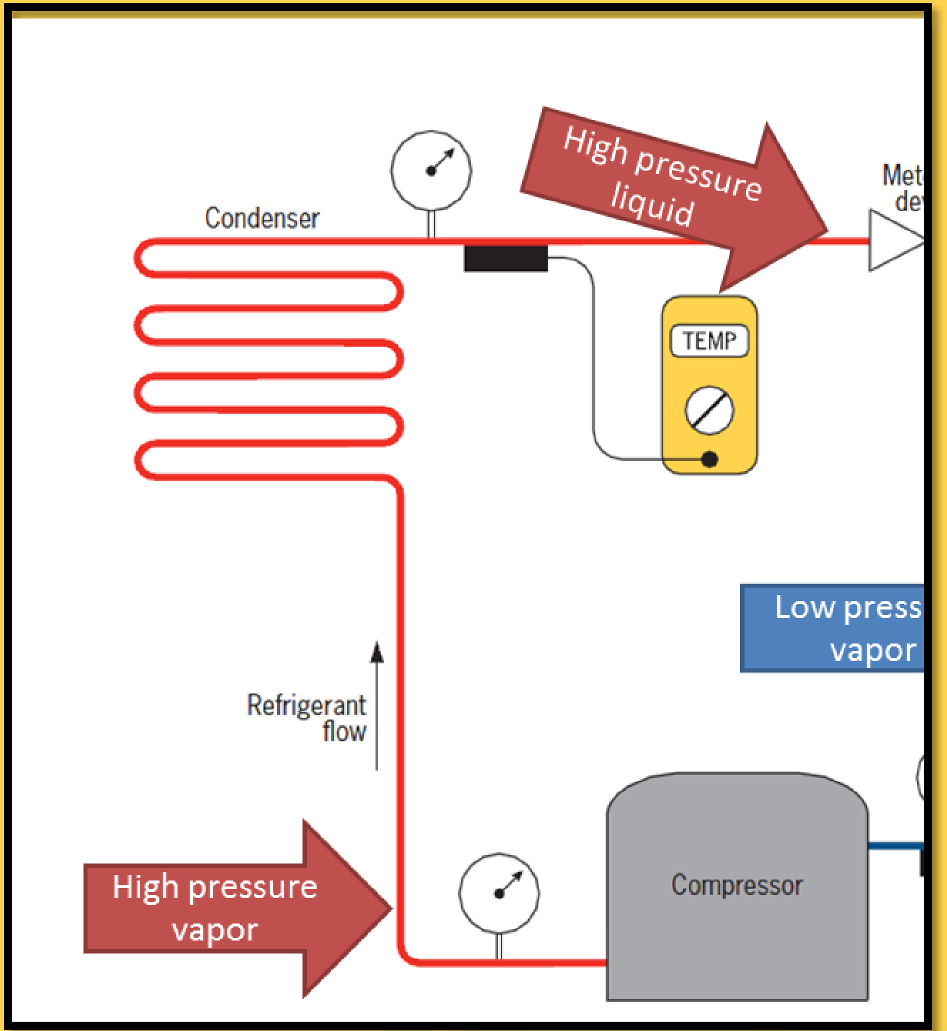
Basic Refrigeration Cycle

- The compressor pumps vapor:
  – Maintains low pressure and boiling temperature in the evaporator.
  – Increases the pressure and condensing temperature in the condenser.



Basic Refrigeration Cycle

- Condensers:
  - Typically need to operate 15 to 25 degrees warmer than the air entering the condenser.

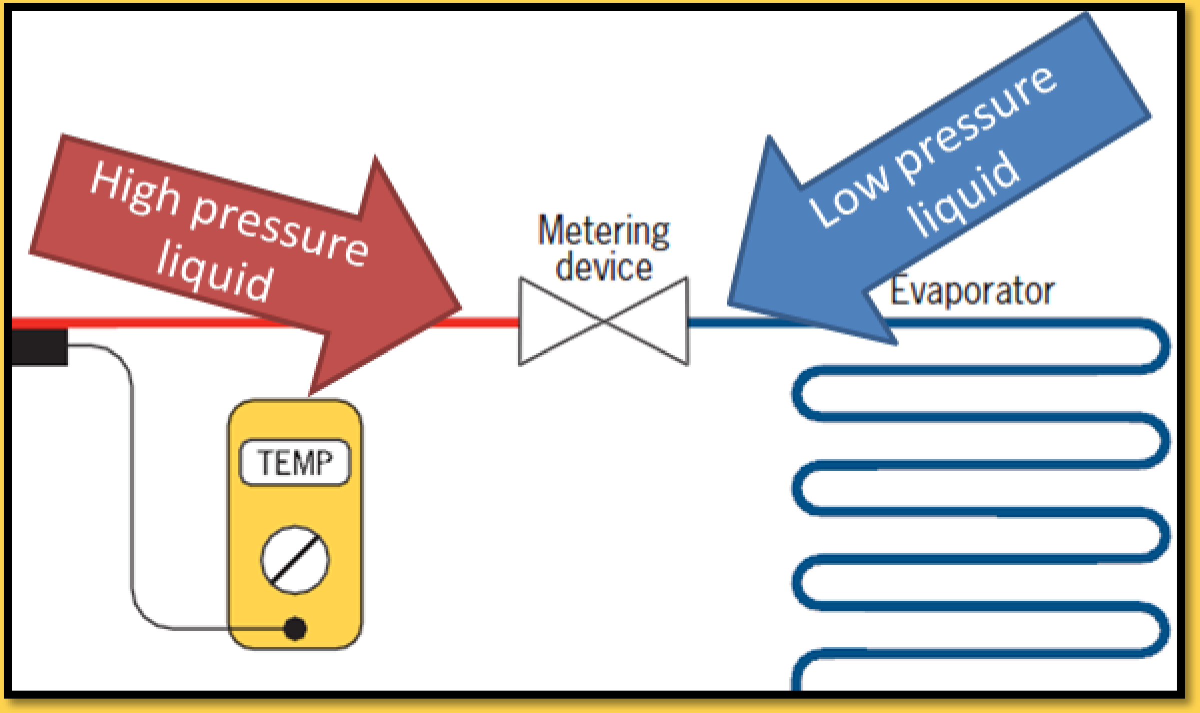


Basic Principles

- Subcooling:
  - Sensible heat removed from a liquid to lower its temperature below the saturation temperature:
    - Ensures 100% liquid to metering device.

Metering Device

- Creates a pressure drop, reducing the boiling point of the refrigerant.
- Fixed bore or thermal expansion valve.



System Components

Chapter 3

Lesson Objective

- Component Review
  - Compressor.
  - Condenser.
  - Metering device.
  - Piping.
  - Refrigerant.

Introduction

- Air conditioning is the process of cleaning, tempering, and humidifying or dehumidifying indoor air and distributing it throughout the conditioned space quietly.
- Filtration also is important.
- Systems are designed with individual pieces.
- Technicians must understand all components.

Compressors

- Heart of the system.
- Serves as a pump:
  - Circulates refrigerant; and
  - Compresses low-pressure vapor to high-pressure vapor.
- Operation of other system components is dependent on the compressor.

Pumping Ratio

- Also called “compression ratio.”
- Absolute discharge pressure divided by absolute suction pressure:

  Ex: 240 psig discharge pressure, 75 psig suction pressure;

  – Discharge Psia = 240 +15 = 255;
  – Suction Psia = 75 + 15 = 90;
  – Compression ratio = 255 ÷ 90 = 2.83;
  – Compression ratio = 2.83:1; and
  – No higher than 4:1.

Hermetic Compressor

- Internal parts not serviceable.
- Cooled by suction vapor.
- Heat-pump compressors run hotter than A/C applications.

Mineral Oils/Lubrication

- Lubricant is important.
- Oil selection is application-specific.
- Oil travels through the system with refrigerant and tends to migrate.
- Crankcase heater boils off liquid refrigerant from oil in the compressor crankcase.

Compressor Types

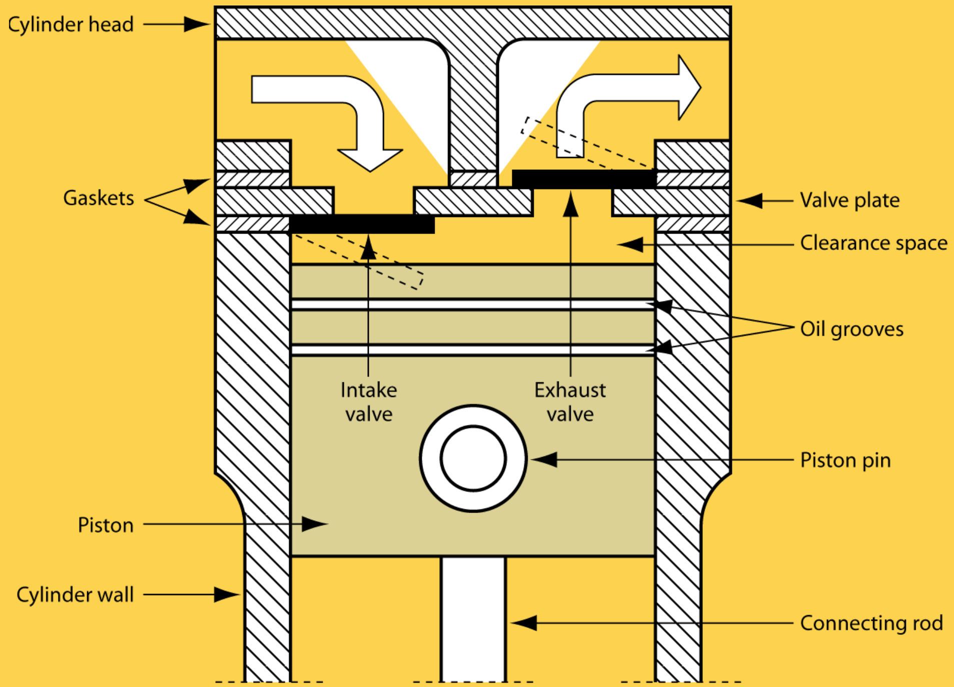
- Reciprocating.
- Scroll.
- Rotary.
- Screw.
- Centrifugal.

Compressors: Vapor Pumps

- Not designed to pump liquid.
- No compressor type can accomplish this:
  - Scroll compressors can let a small amount of liquid pass though.
- Compressor must have refrigerant vapor ONLY at the suction inlet.

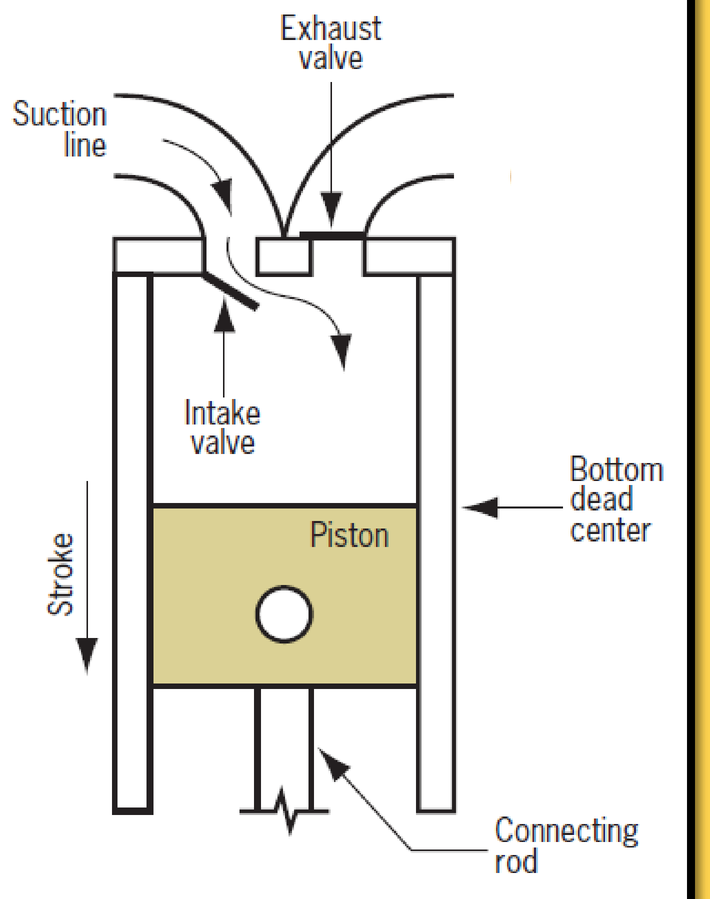
Compressors: Reciprocating

- Rotating motion of the motor is converted to reciprocating motion of the piston.
- Four stages of compression:
  - –Re-expansion;
  - –Suction (intake);
  - –Compression; and
  - –Discharge.



Compressors: Reciprocating

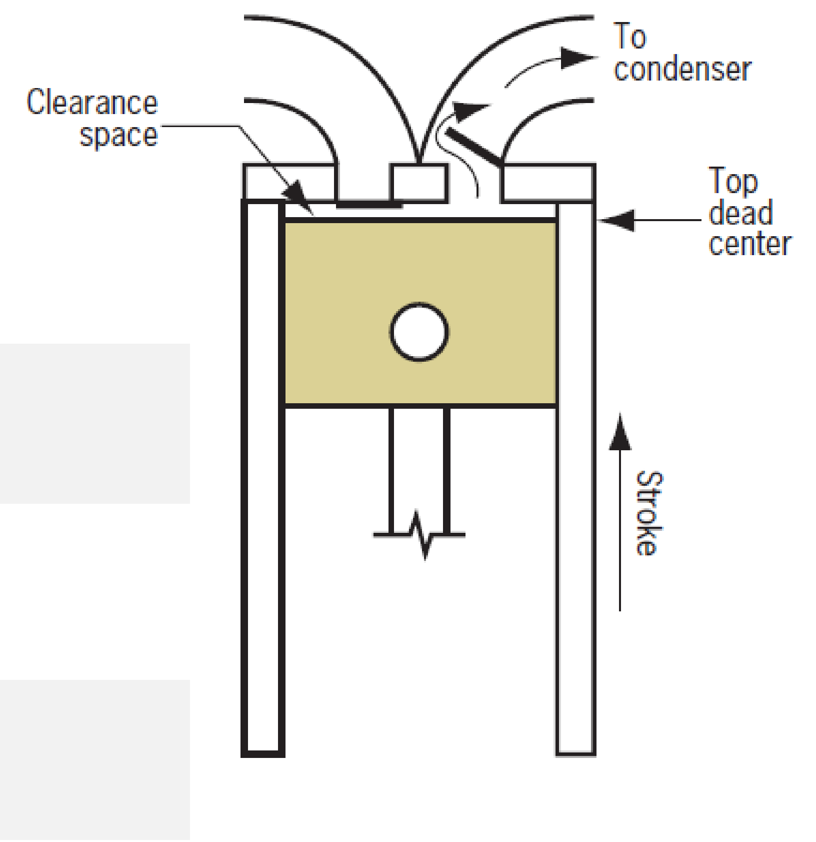
- Intake: vapor is drawn into cylinder:
  - "Suction."
  - Continues until the piston reaches its lowest point in the cylinder, or bottom dead center.



A. Suction (intake) stroke

Compressors: Reciprocating

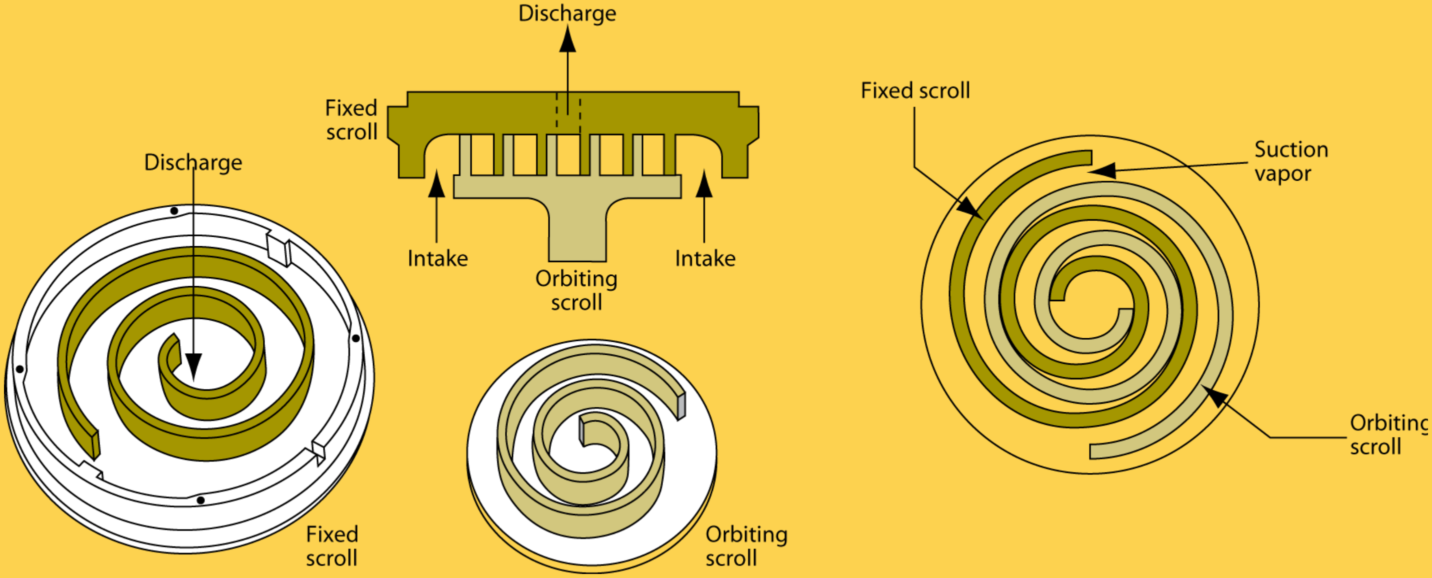
- The trapped vapor increases in pressure when the volume in the cylinder decreases as the piston makes its way toward top dead center again.
  - "Compression."
- When the cylinder pressure is greater than the discharge pressure, the discharge valve is pushed open, allowing high-pressure hot vapor to enter the discharge line.
  - "Discharge."



B. Compression (exhaust) stroke

Compressors: Scroll

- Fixed and orbiting scroll.
- Continuous compression process.
- Illustrated on the next slide.



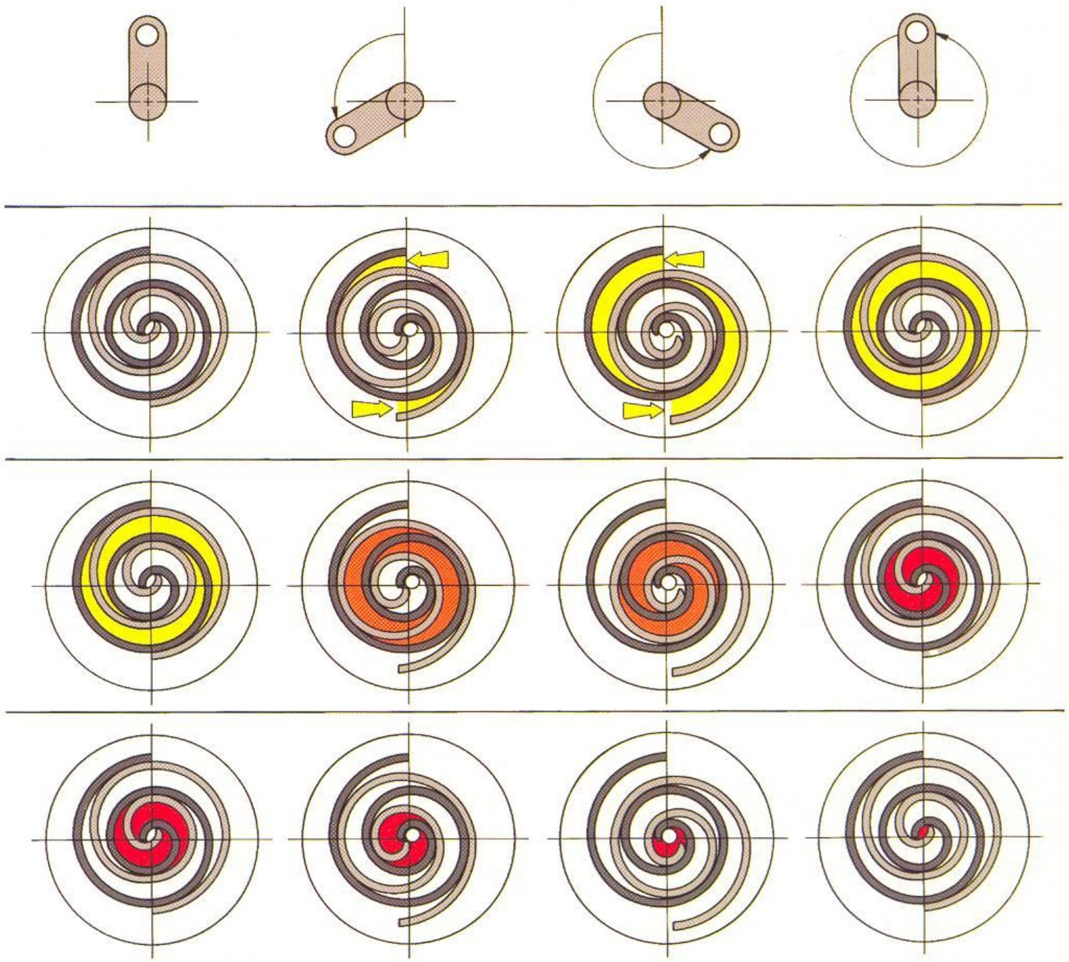
Compressors: Scroll

General
A 3-D compressor has two scrolls. The top scroll is fixed and the bottom scroll orbits. Each scroll has walls in a spiral shape that intermesh.

Inlet — First Orbit
As the bottom scroll orbits, two refrigerant gas pockets are formed and enclosed.

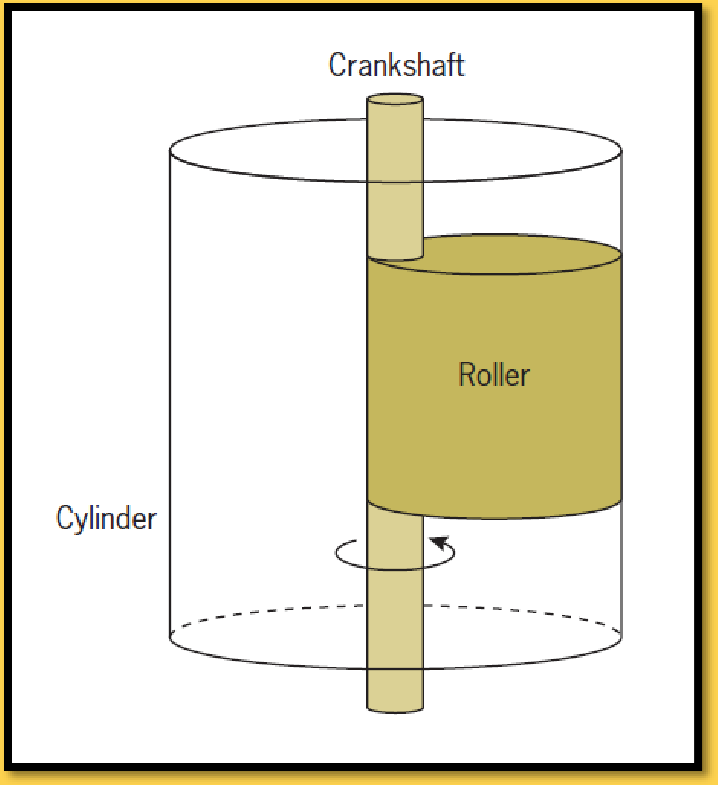
Compression — Second Orbit
The refrigerant gas is compressed as the volume is reduced closer to the center of the scroll.

Discharge — Third Orbit
The gas is compressed further and discharged through a small port in the center of the fixed scroll.

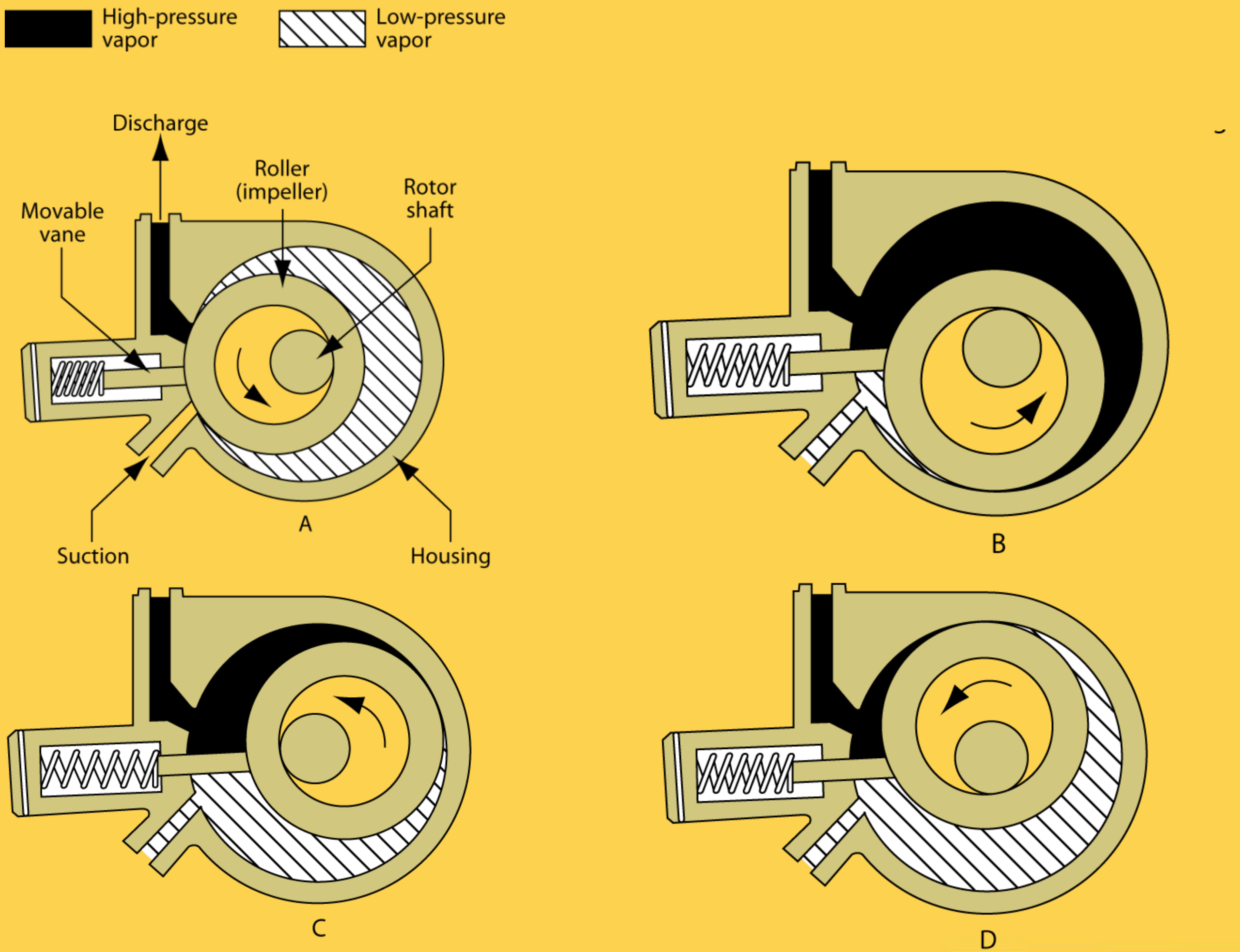


Compressors: Rotary

- Cylindrical shape.
- Eccentric roller attached to the crankshaft.
- Compression process (four basic steps):
  - Induction of suction vapor into the compression chamber;
  - Sealing off of the suction chamber, trapping refrigerant inside;
  - Compression of the refrigerant; and
  - Discharge of the high-pressure refrigerant from the compressor.



Rotary Compression Cycle



Compressor Motor Cooling

- High temperature and fully hermetic compressors are typically refrigerant cooled.
- Flow of the cool refrigerant vapor is directed across the motor before it enters the head of the compressor to cool the motor.
- High superheat or reduced suction pressure will reduce motor cooling capacity.

Condenser

- The condenser must reject heat from multiple sources:

  Heat absorbed in the evaporator;

  – Heat added in the suction line;

  – Heat added in the liquid suction heat exchanger;

  – Heat of compression; and

  – Heat from the compressor motor on refrigerant-cooled compressors.

Condenser

- The refrigerant will enter the condenser as a highly superheated vapor:
  - Temperature must be dropped to saturation point.
- The refrigerant is condensed:
  - Latent heat is removed.
- The refrigerant must be subcooled:
  - This ensures that all refrigerant has condensed and refrigerant won’t flash off in the liquid line due to pressure drop.

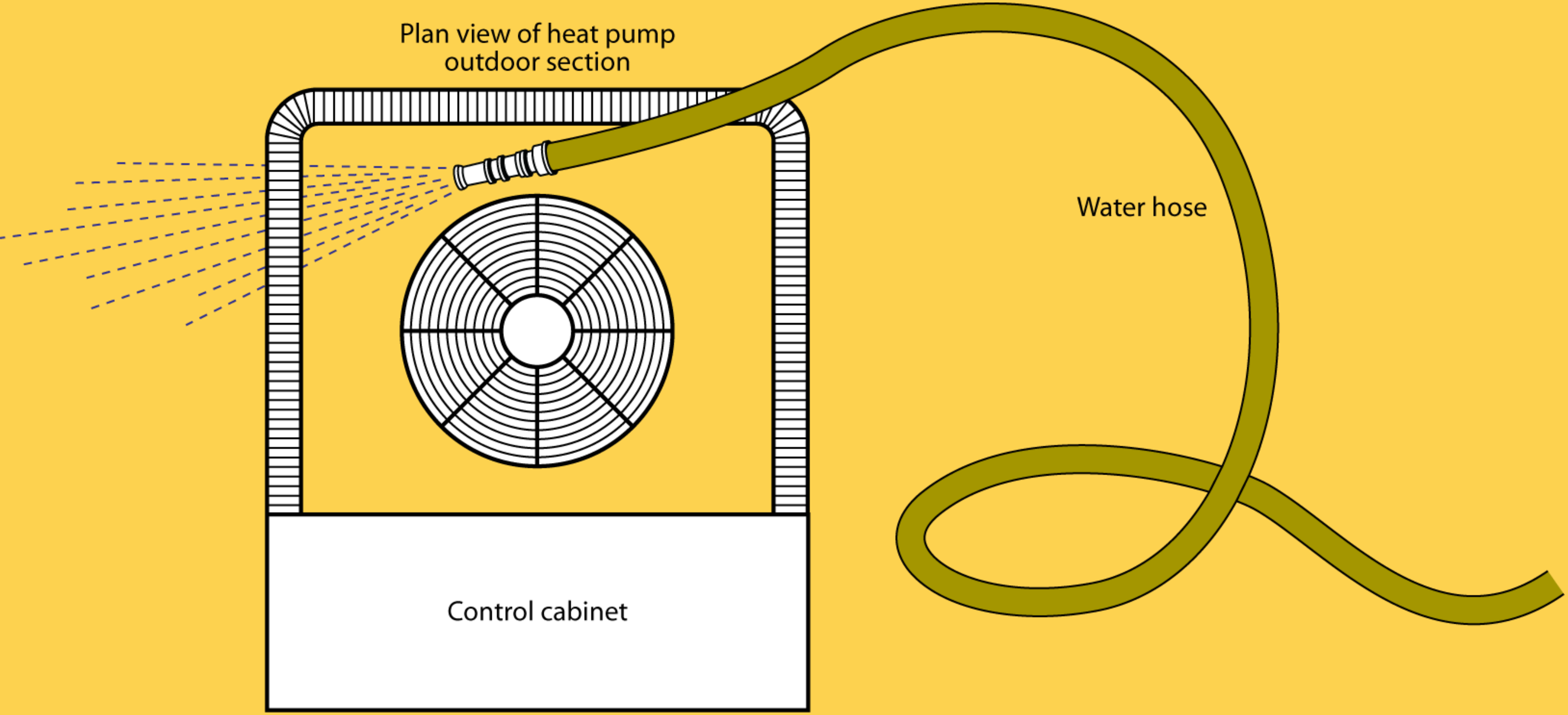
Condensers

- Larger coil surface increases the rate of heat transfer.
- Proper matching to indoor coil is critical.

Condensers

- Only manufacturer-approved matches should be installed.
- Heat-pump coils typically have more circuits than cooling-only systems.

Flushing condenser coil



Condensers

- Condensing temperature of lower-efficiency condensers is approximately 30°F higher than the outdoor air temperature.
- Higher-efficiency systems may have condensing temperatures that are less than 20°F higher than the outdoor air.

Water-cooled Condenser

- Closed loop:
  - Water circulates through a loop of pipe buried in the ground, run through a building, or a secondary heat exchanger (dry cooler).
- Open loop:
  - Water pumped from a source and dumped; and
  - Cooling tower (commercial).

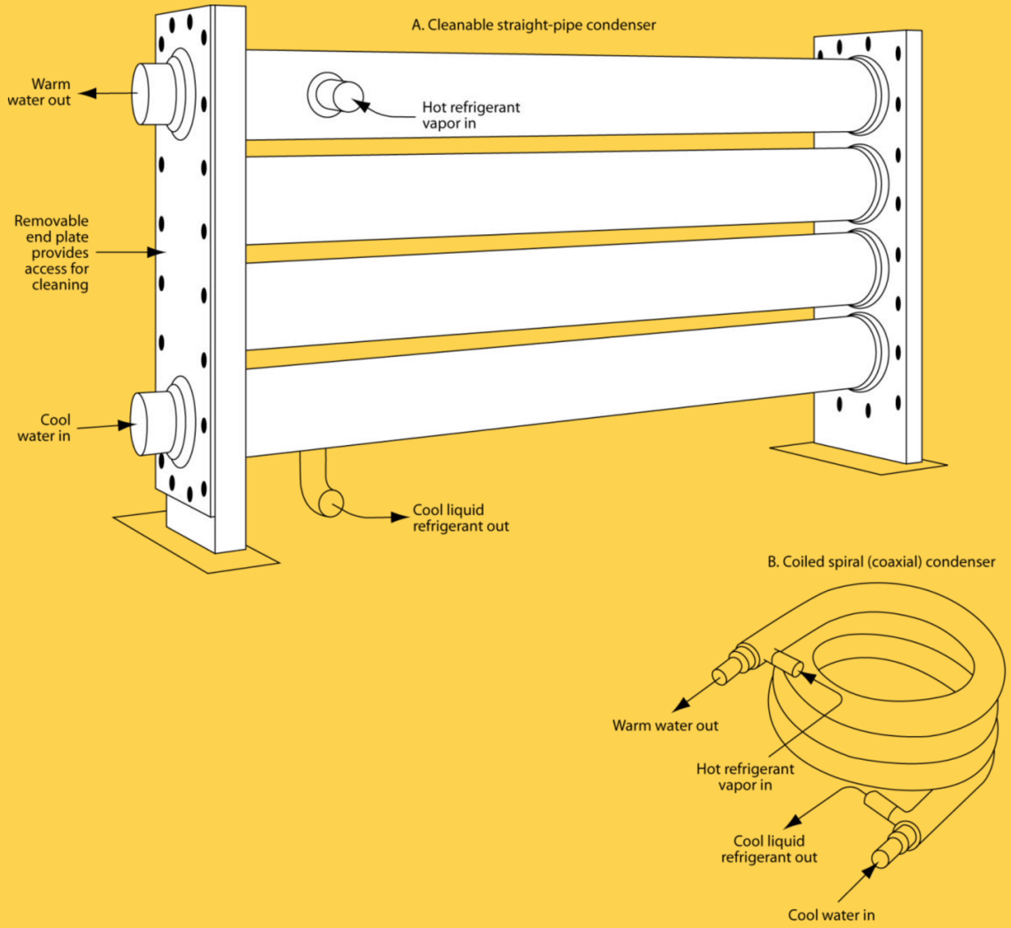
Water-cooled Condenser: “Pump and Dump”

- Also called “wastewater” system:
  - Expelled to drain or lawn.
- The water-regulating valve should be adjusted to maintain a leaving water temperature of 100°F.
- The water flow rate through condensers used in wastewater systems is approximately 1.5 gpm (gallons per minute) per ton of cooling.

Water-cooled Condenser

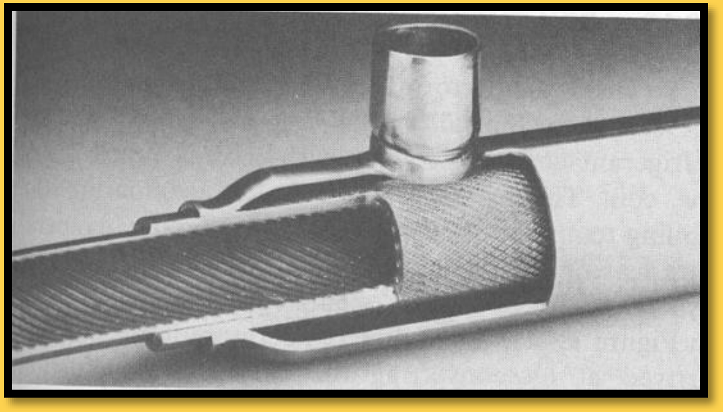
There are three common types of water-cooled condensers. Each is classified by its method of construction, as follows:

- Tube-in-tube;
- Shell-and-coil; and
- Shell-and-tube.



Water-cooled Condensers: Tube-in-tube

- Liquid flows through the inner tube with refrigerant evaporating around the outside.

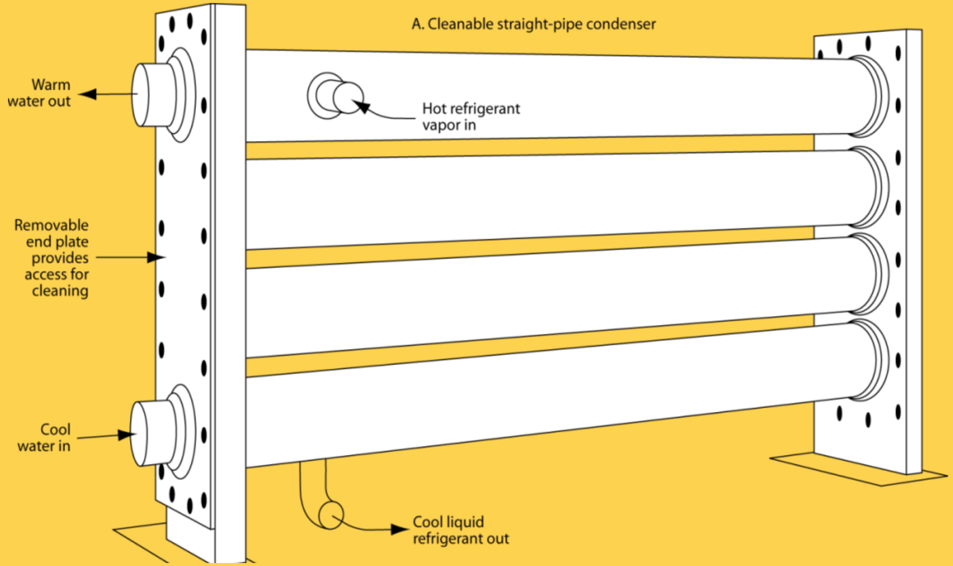


- Normally used on smaller load applications.

Water-cooled Condensers: Tube-in-tube

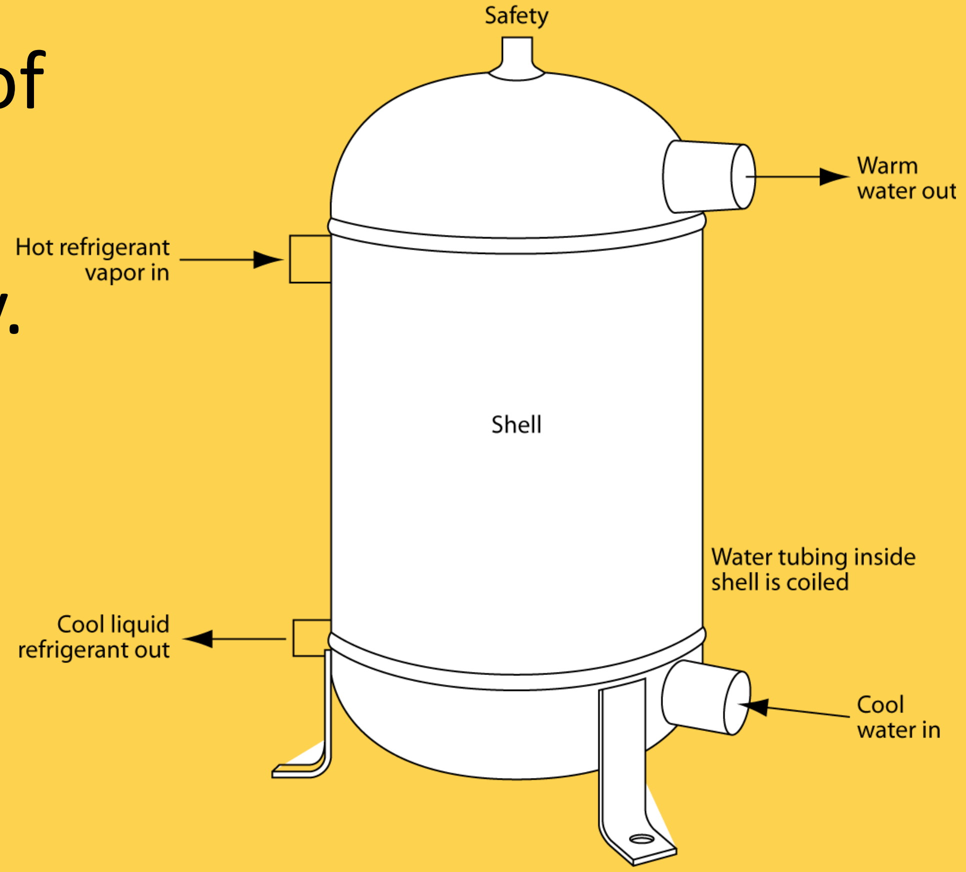
Maintenance:

- End plates can be removed; and
- Water circuit is cleaned with special brushes.



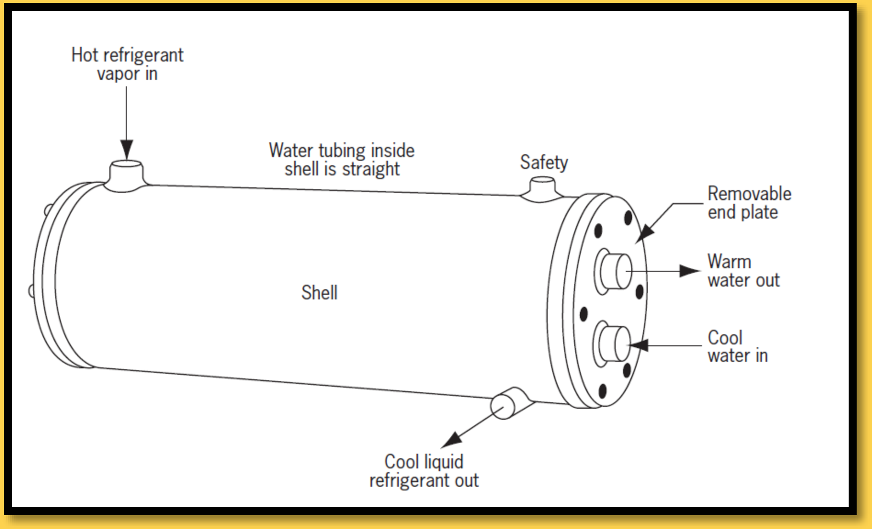
Vertical Shell-and-coil Condenser

- Steel shell with coils of tubing.
- 3 ton–15 ton capacity.
- Also serves as a receiver.
- Must be chemically cleaned.



Water-cooled Condensers: Shell-and-tube

- Superheated refrigerant enters the shell.
- Heat is transferred into the cooler water tubes.
- The refrigerant condenses to liquid.
- The liquid is subcooled and stored until needed in the evaporator.



Metering Devices

- Also called an “expansion device.”
- Create a pressure drop.
- Feed liquid refrigerant into the evaporator.

Metering Devices: Fixed

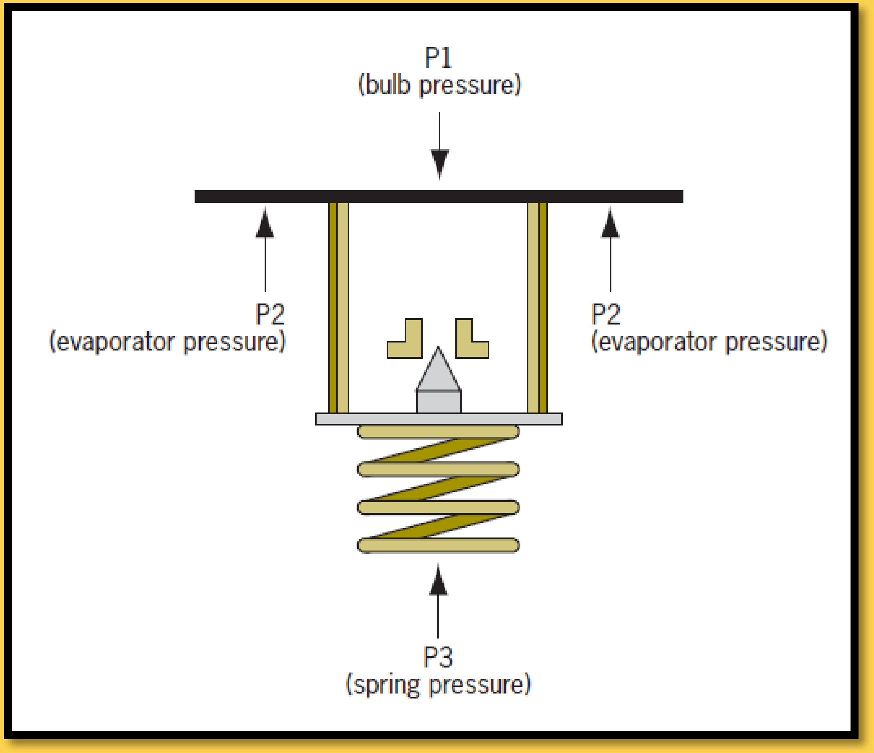
- Fixed orifice and capillary tube:
  - The capillary tube is a simple and inexpensive device.
  - The flow rate is determined by its length and inside diameter.
  - Used on smaller refrigeration systems.

Metering Devices: TXV

- Thermostatic Expansion Valve:
  - TXV or TEV.
- Three pressures:
  - Bulb;
  - Evaporator; and
  - Spring.

Metering Devices: TXV

- Bulb (P1) vs. evaporator (P2) + spring (P3) pressures.
- Maintains superheat at the exit of the evaporator.



Externally Equalized TXV

- Allows measurement of the evaporator pressure at the outlet of the evaporator.
- Prevents “hunting”—alternate overfeeding and starving of the evaporator.

Balanced Port Valve

- When the condensing pressure is allowed to float it will affect valve operation since the liquid line pressure is normally one of the forces that opens the valve.
- The balanced port valve takes the liquid-line pressure out of the equation.

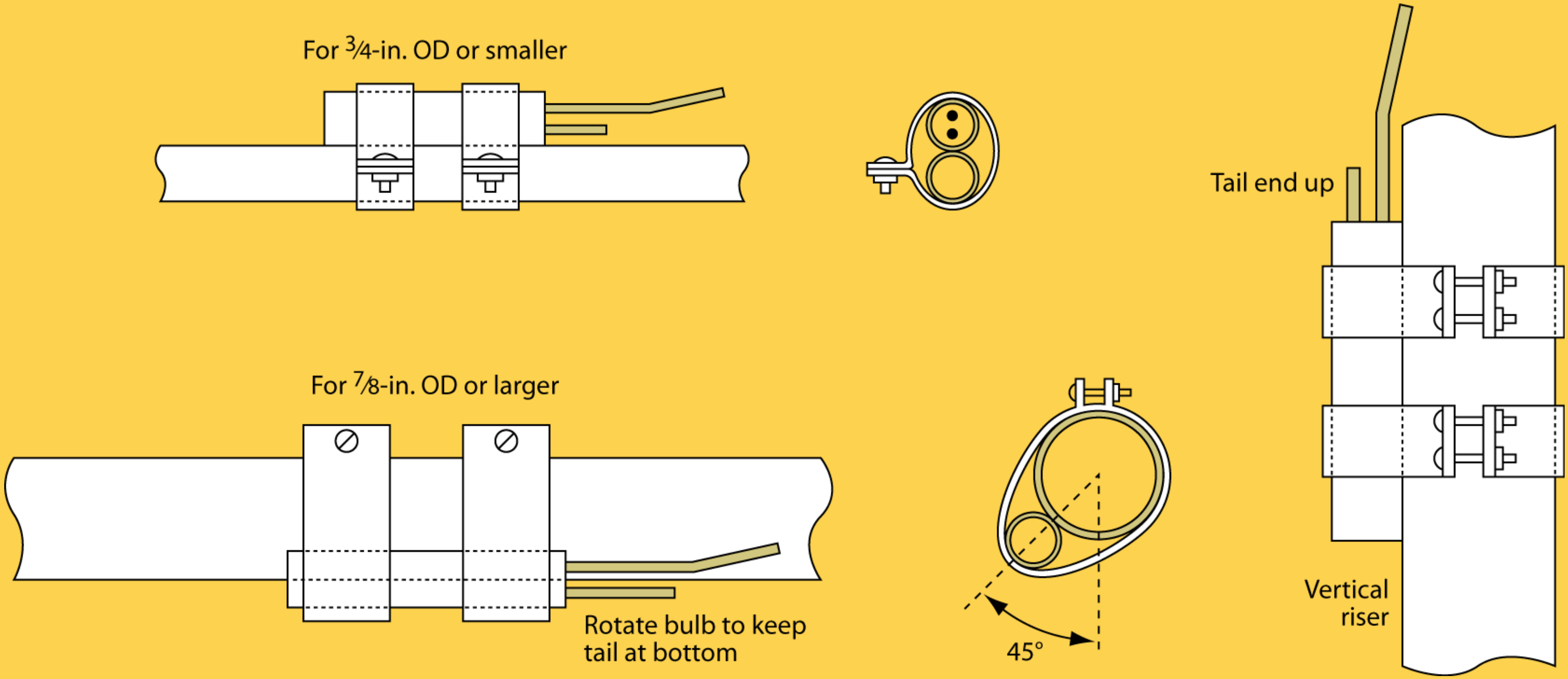
TXV Bulb Charge

- Liquid charge:
  – Bulb charge matches system charge.
- Vapor charge;
  – Bulb charge matches system charge but bulb charge is limited to provide a maximum operating pressure.
- Liquid or vapor cross charge:
  – Bulb charge is different from system charge (pressure temperature relation crosses that of the system charge). This will speed or slow the valves reaction to temperature change.

Sensing-bulb Location

- The sensing bulb must be securely mounted to the suction line.
- The sensing bulb must be properly insulated.
- The sensing bulb my be located on the top of ⅞-in. or smaller lines.
- The sensing bulb should be mounted at the 4 o’clock or 8 o’clock position on larger lines.

Sensing Bulb locations



TXVs Require Liquid Input

Faults that could create unacceptable pressure drops across the liquid line (and thus liquid-vapor mixture to TXV) include:

- Restricted liquid-line filter-drier;
- Excessively long liquid line;
- Liquid-line tubing diameter that is too small;
- Kinked liquid-line tubing; and
- Insufficient refrigerant charge.

Evaporators

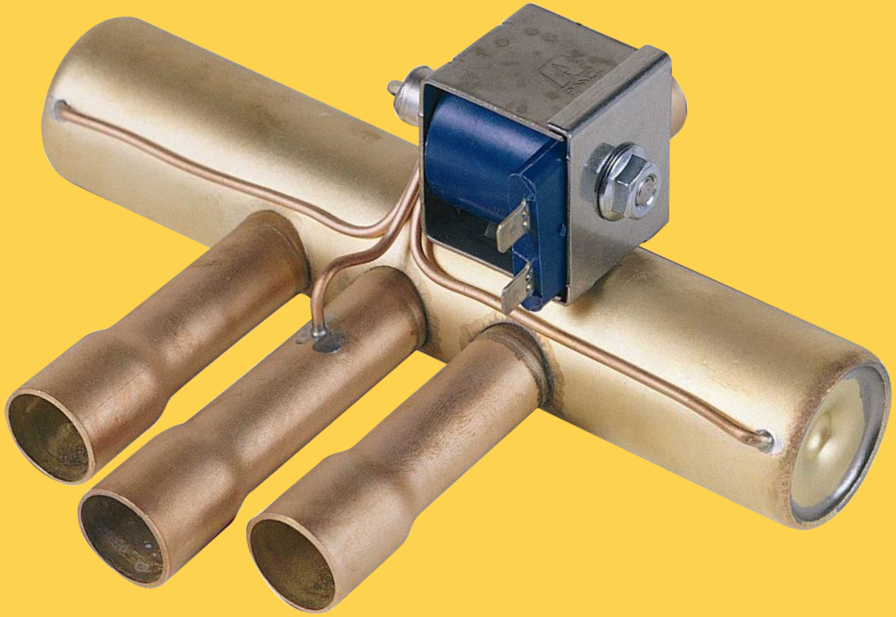
- The evaporator will boil the refrigerant and absorb heat from the air or water.
- An air-conditioning evaporator must operate at a temperature below the dew point of the air.
- A larger size coil will contain multiple parallel circuits to reduce pressure drop.
- A distributor ensures even flow of the refrigerant into all circuits.

Evaporators

- Types:
  - A-coil; and
  - Horizontal slab.
- In heat pumps the outdoor coil becomes the evaporator during the heating mode.

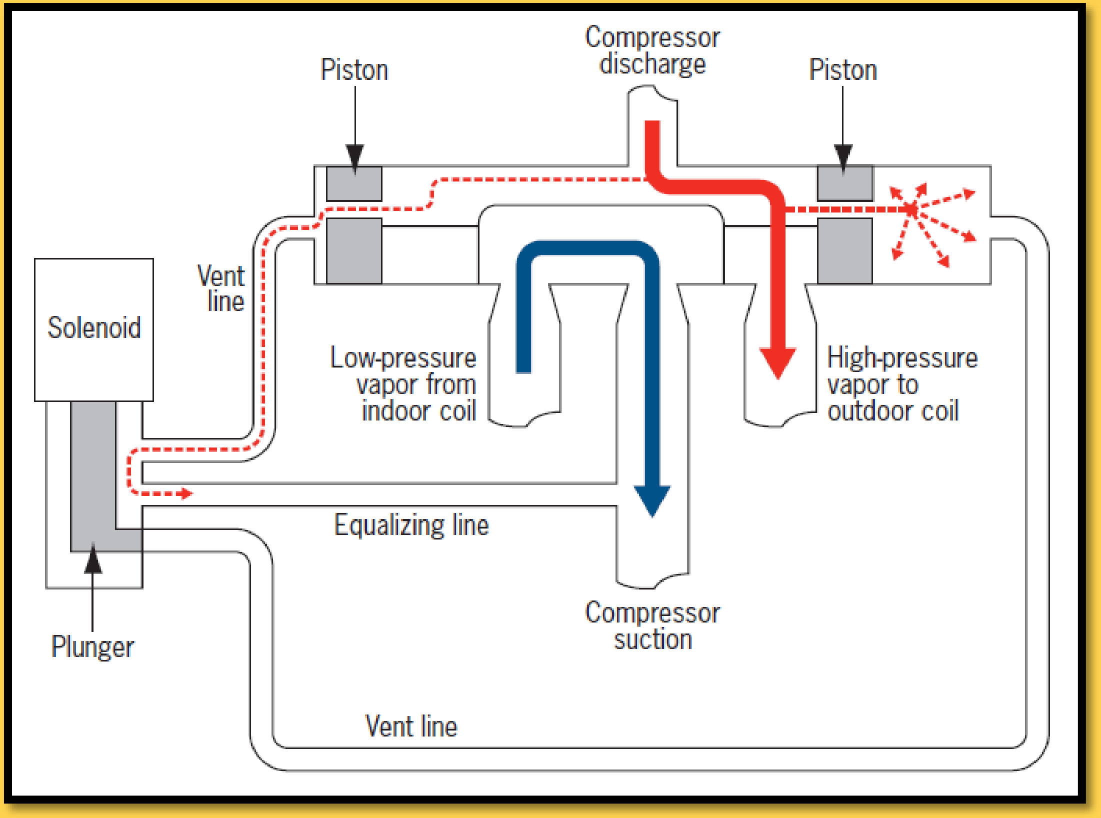
Reversing Valve

- The reversing valve is used in a heat pump to switch from heating to cooling.
- Some systems will energize the reversing valve in the cooling mode and others in the heating mode.



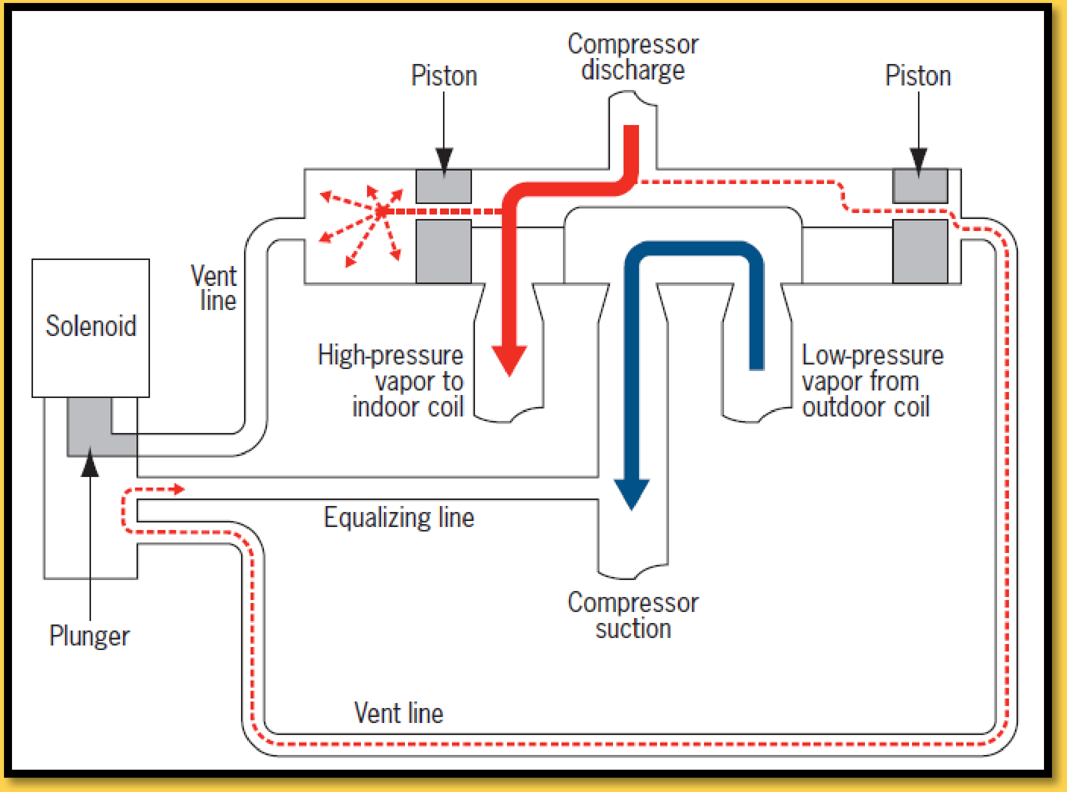
Reversing Valve

- Two pistons and ported sliding block.
- Pilot valve.
- Shown in cooling mode.



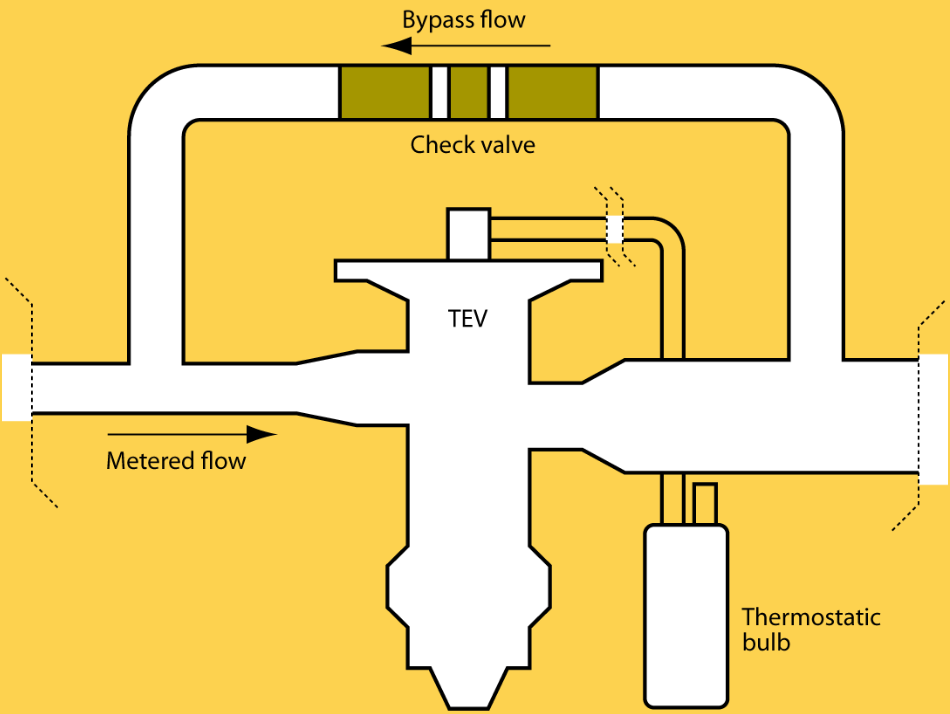
Reversing Valve

- Shown in heating mode:
  - Discharge is directed to the indoor coil.
- Refrigerant charge is important to proper operation.



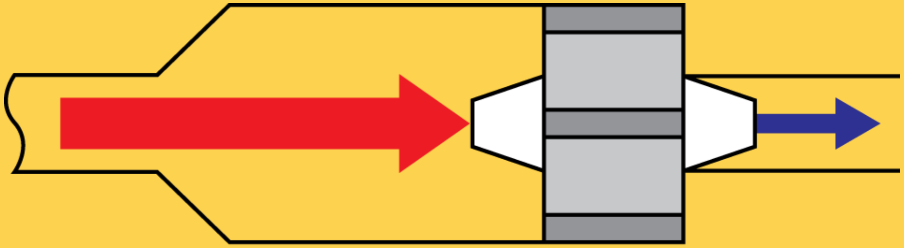
Check Valve and TEV

- Prevents flow in one direction.
- Used in heat pumps as mode of operation changes.
- Defective check valve can cause low head and high suction pressure:
  - Just as defective valves in the compressor.

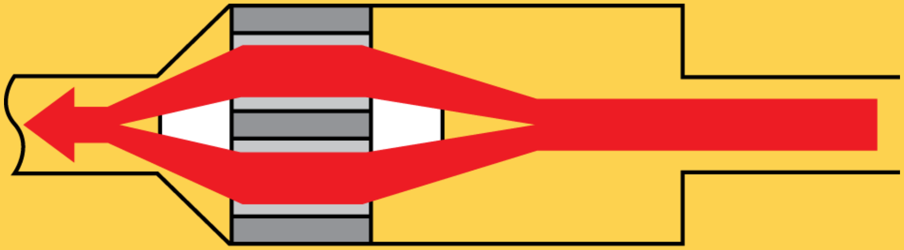


Check Valve and Metering Piston

- Orifices may allow refrigerant metering or bypass depending on the position in the housing.



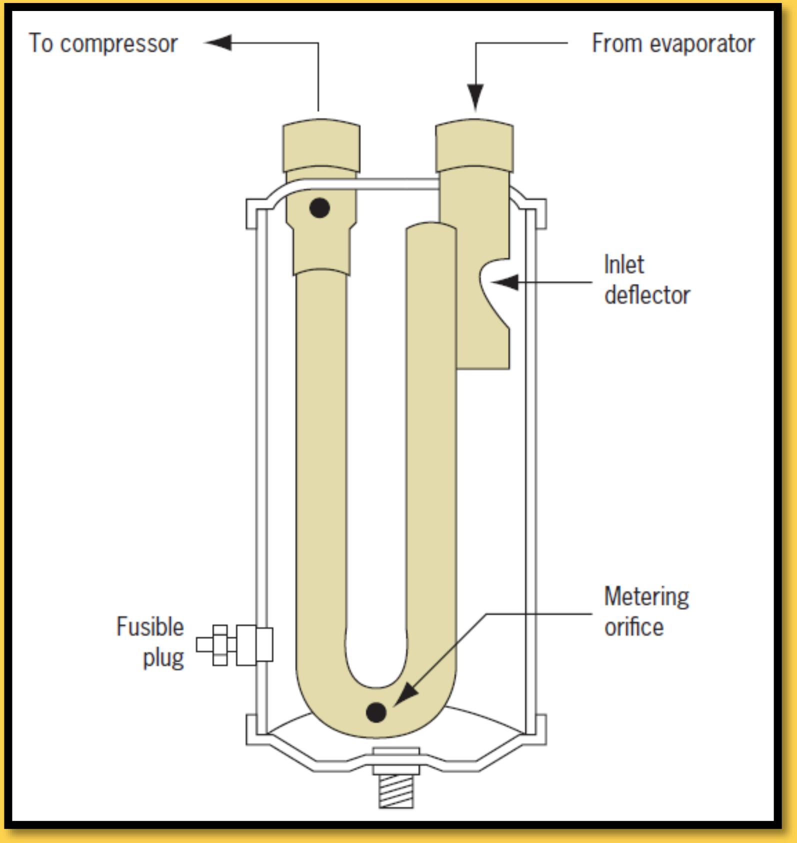
Piston in metering position



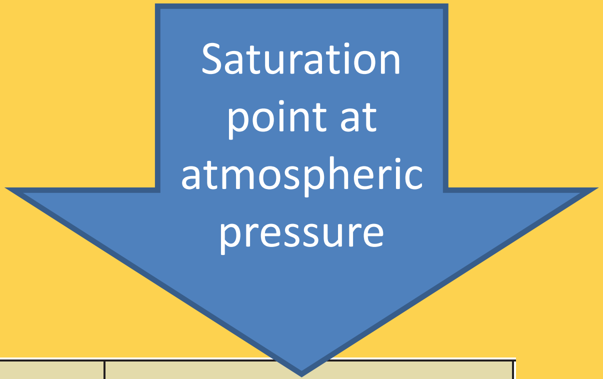
Piston in bypass position

Accumulators

- Accumulators are added to the suction line to collect and boil off any liquid refrigerant in the suction line before it can reach the compressor.
- Receivers store refrigerant:
  - Optional component.
  - Located between the condenser and the metering device.



Refrigerants



- R-22:
  - Mineral oil.
- R-410A:
  - Polyolester (POE) oil.
  - No ozone depletion.

Refrigerant	Temperature
R-12	–22°F
R-22	–42°F
R-410A	–63°F
R-500	–28°F

Refrigerants

- Decomposition occurs if refrigerant is exposed to high temperatures:
  - Never solder or braze without purging the piping with nitrogen and ventilating the area.
- Inhaling concentrated vapors can cause heart irregularities and unconsciousness.

Refrigerant Cylinders

- DOT has jurisdiction over shipping and labeling of cylinders.
- Maximum storage temperature is 125°F.
- Never fill more than 80%.

Tubing

- Approved for ACR applications.
- Inspect and leak-test all soldered and brazed joints.
- Leak test with dry nitrogen:
  - Never use compressed air; and
  - Never use oxygen.
- Purge lines with nitrogen when brazing.
- Use neutral flame with oxyacetylene torch.

Piping

- Keep lines as short as possible.
- Use long-radius elbows.
- Keep fittings to a minimum.
- Pitch vapor lines toward the compressor.
- Insulate vapor lines:
  – Liquid lines in high temperatures.

Piping

- Inspect and leak-test all brazed and soldered joints.
- Install traps on vertical risers when necessary.
- Keep tubing capped to keep it clean.
- Evacuate system to at least 500 microns.

Piping

- Use of soft-drawn copper can reduce the number of fittings.
- Bend soft-drawn tubing with spring or lever bender.
- Never cut with a hacksaw.
- Pressure drop in a suction line should not exceed 2°F.

Piping

- Bending tools can only be used on soft-drawn copper.
- Length and diameter are important.
- Excessive pressure drop across a liquid line must be avoided. These causes include:
  - Excessive liquid-line length;
  - Excessive liquid-line lift;
  - Tubing diameter that is too small;
  - Kinks in the liquid line; and
  - Too many elbows and/or the use of short-radius elbows.

Summary

- By adding a reversing valve and check valves to a system, the basic refrigeration cycle can be manipulated to provide heating in winter as well as cooling in summer.
- In order to service comfort cooling and heat pump systems successfully, a technician must understand the principles at work in a closed vapor compression cycle.
- The term “closed” indicates that the cycle continually repeats itself without depleting the refrigerant contained within it.

Electrical Components

Chapter 4

Electrical Components
Lesson Objectives

- Principles of electricity
- Types of motors
- Compressors
- Relays, contactors and starters
- Capacitors
- Transformers
- Thermostats
- Safety controls
- Defrost controls
- Electrical heaters
- Miscellaneous controls

Introduction

- The work done by any vapor-compression system is accomplished through the use of components operated by electric power.
- Connecting wires form circuits that provide paths for electric current:
  - Any interruption in the electric circuits will cause the system to fail to operate as it is designed to do.
- A thorough understanding of the key electrical components that make up these systems is required.
- You must have a good working knowledge of the principles of electricity.

Voltage

- Electrical pressure.
- Electromotive force:
  - "E" in ohms law calculation:
    - It takes 1 volt (1 V) to push 1 amp (1 A) through 1 ohm (1Ω) of resistance.

Current

- Movement of electrons in a conductor.
- Measured in amperes.
- Intensity:
  - “I” in ohms law calculation.

Resistance

- Opposition to the flow of current.
- Measured in ohms.
- “R” in ohms law calculations.

Power

- Rate of doing work.
- Measured in watts.
- “P” in calculations.
- Power factor must be applied for inductive loads:
  - True power (watts) ÷ apparent power (VA).

Loads

- Components that consume power to do useful work.
- Voltage drop is measure by connecting the voltmeter in parallel to the energized load.

Switches

- Pass power through without consuming power.
- No voltage drop (0 volts) will be measured across a closed switch supplying power to an operating load.
- A voltage drop measured when connected in parallel across a switch indicates an open switch.
- A voltage reading across a switch also could indicate bad contacts (usually less than full voltage).

Power Source

- Electric power to the building.
- Single-phase.
- Three-phase.

Path

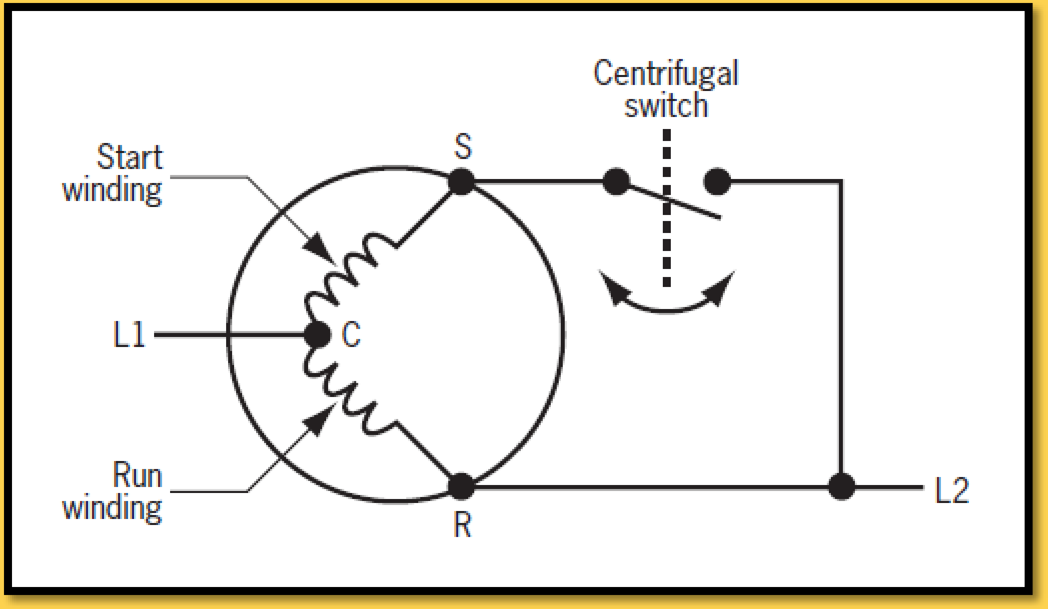
- Wires and components that complete the circuit.
- From the power source to the load and back to the source.

Motors: Shaded Pole

- Low starting torque.
- Low efficiency.
- Small loads such as fans.

Motors: Split Phase

- Start and run winding:
  - Higher resistance in the start winding creates a phase shift to improve starting torque.
- Medium starting torque.
- Centrifugal switch is often used to take the start winding out of the circuit.
- Capacitors are added in different configurations to improve efficiency (run cap.) and improve starting torque (start capacitor).



Compressors

- Typically the largest motor in the system.
- Open drive:
  - Motor is external of refrigerant circuit.
- Semi-hermetic:
  - Can be rebuilt.
  - Can be cooled by suction gas.
- Hermetic:
  - Motors are cooled by the suction gas.
  - Motor burn out will contaminate system.
  - Cannot be repaired in the field.

Two-speed Compressors

- Two-speed compressor motors can be used to more closely match the system output to the load.
- Staging is based on deviation from setpoint of the room thermostat.

Compressor Cooling

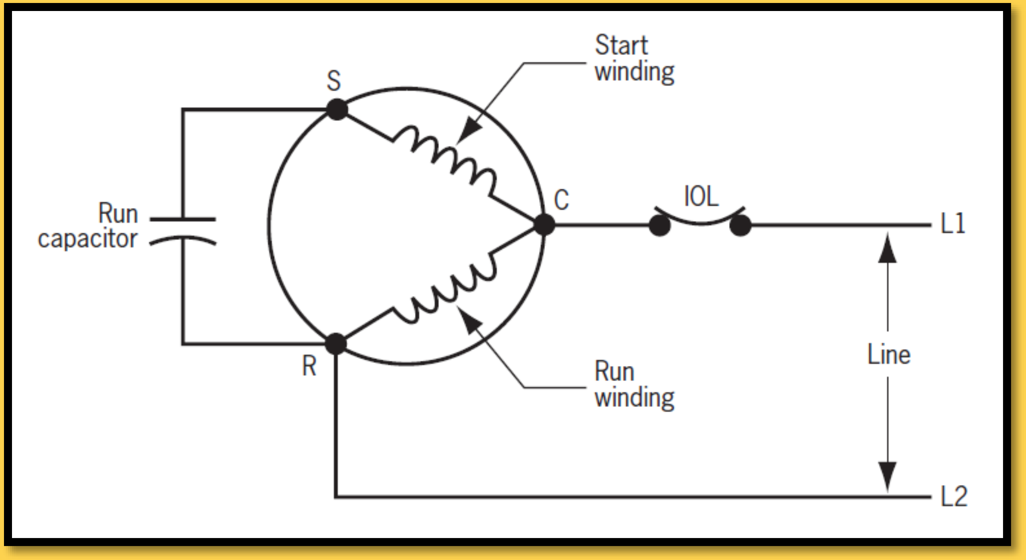
- Cooled by refrigerant vapor.
- Hermetic compressors must never be run in a vacuum:
  - Heat cannot be dissipated and motor damage will result.

Ratings

- RLA – Rated load amps.
- MCC - Maximum continuous current:
  - Maximum current that won't trip the overload.
- The minimum RLA value that can be published by the manufacturer is the MCC divided by 1.6.

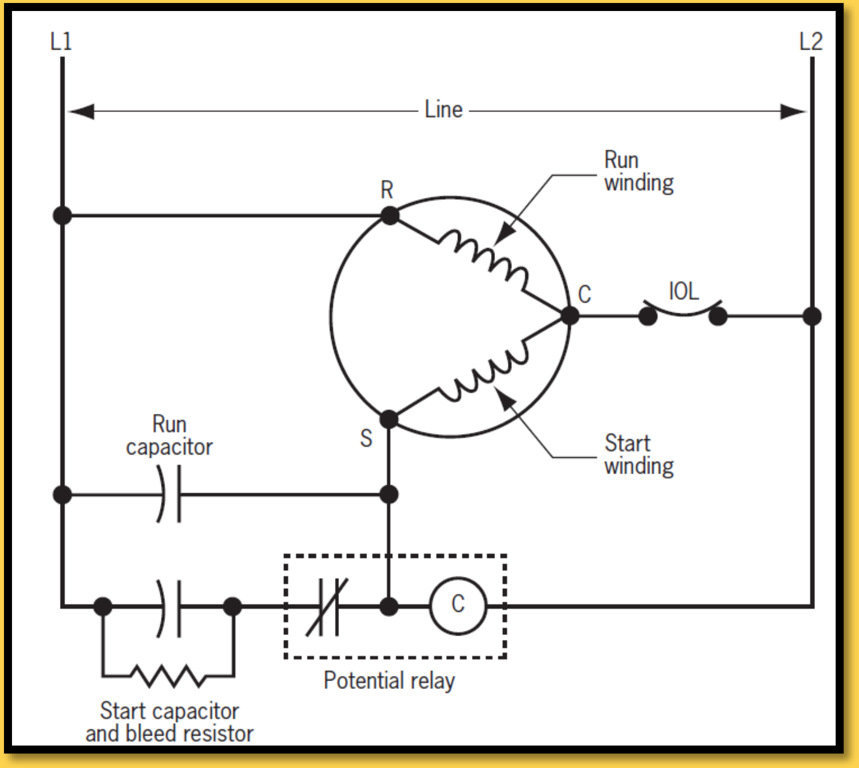
Compressor Motors: PSC

- Single phase.
- Run capacitor is connected between run and start windings.
- Applied to systems that have rapid pressure equalization on shutdown.



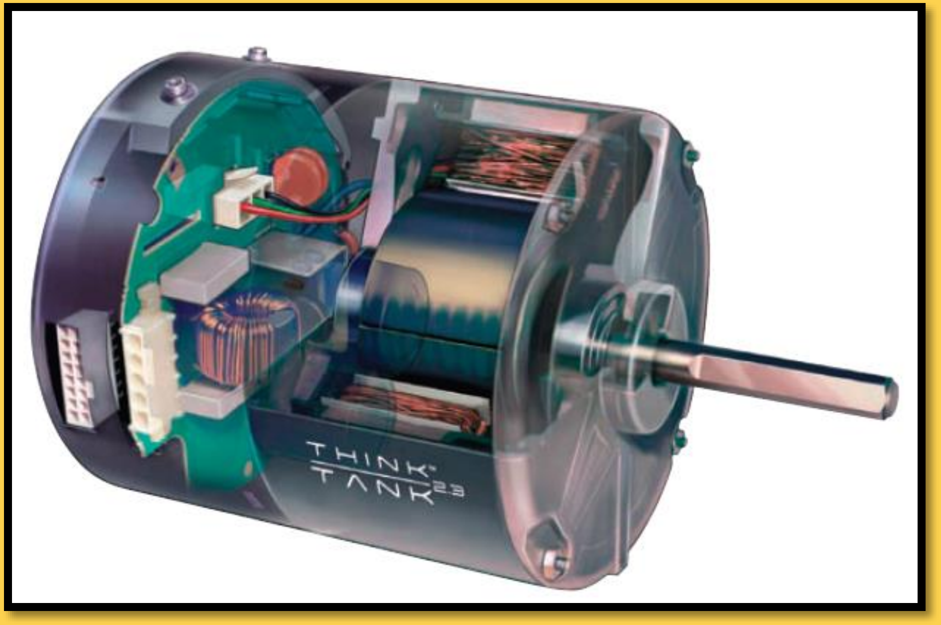
Compressor Motors: CSCR

- Start and run capacitors are used.
- Both are in the circuit during start-up.
- Start relay opens when motor gets up to speed.
- Run capacitor remains in the circuit.



ECM

- Electrically Commutated Motor:
  - Electronically controlled brushless DC motor.
- Used primarily on blower motors at the present time:
  - Provides excellent humidity control;
  - Factory-set airflow;
  - Energy-efficient operation;
  - Long life;
  - Low operating temperature;
  - Programmability; and
  - Wide operating range.



Motor Speed

- Synchronous speed:
  - Speed at which the magnetic field rotates.
  - $S_S = 120f \div P$
- Slippage:
  - Synchronous speed – actual speed.

Number of poles in 60-Hz motor	Synchronous speed (rpm)	Rotor speed (rpm)	Slip (%)
2	3,600	3,450	4.17
4	1,800	1,750	2.78
6	1,200	1,050	12.50
8	900	850	5.55

Air Flow

- Air flow delivered from the fan is directly proportional to the speed of the fan.
- Residential systems most commonly use forward pitched blades.
- Multi-tap motors reduce speed because the horsepower is reduced and it can not keep up with the load:
  - It is important to match the horsepower when replacing the motor. A larger hp motor will not slow down.

Motors

- The outdoor unit of residential systems typically use 240-V motors.
- Larger blowers will commonly use belt drives:
  – Adjusting pulley diameters will adjust fan speed.
- Motors over 5 hp are usually three-phase 240-/460-V motors:
  – Rotation can be changed by reversing any two leads.

Grounding

- It is important to maintain a proper ground connection to electrical equipment at all times:
  – Proper grounds reduce shock hazards;
  – Green or bare wire should be used; and
  – Older systems often used the metal conduit to provide a ground path.

Overcurrent Protection

- Fuses are designed to protect conductors, not motors:
  - A standard fuse may be rated up to 300% of the motor's FLA.
  - Time delay fuses should be rated at 125% of the motor's FLA.

Motor Voltage

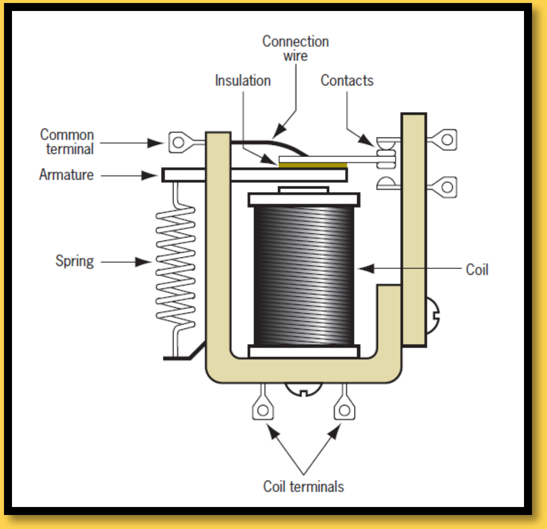
- Actual voltage should not exceed ± 10% of the motor nameplate.
- Motors rated at 208/230 V ac should not drop more than 5% below the 208 V (198 V).

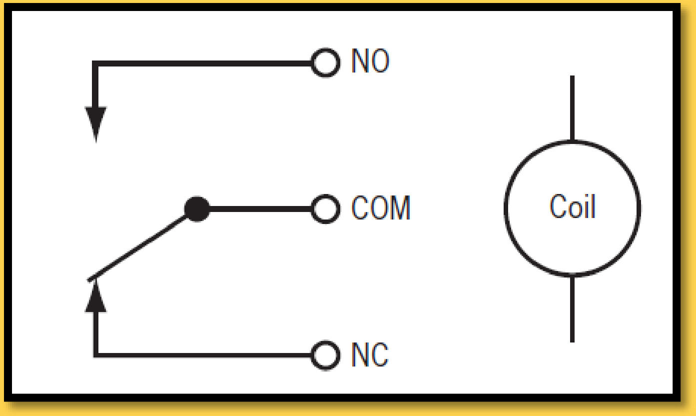
Switching

- Low-voltage controls are most often used to provide switching for line voltage loads and provide safety for the technician. Benefits include:
  - Safer control voltage;
  - More accurate controls; and
  - Meeting of code requirements.

Relays, Contactors, Starters

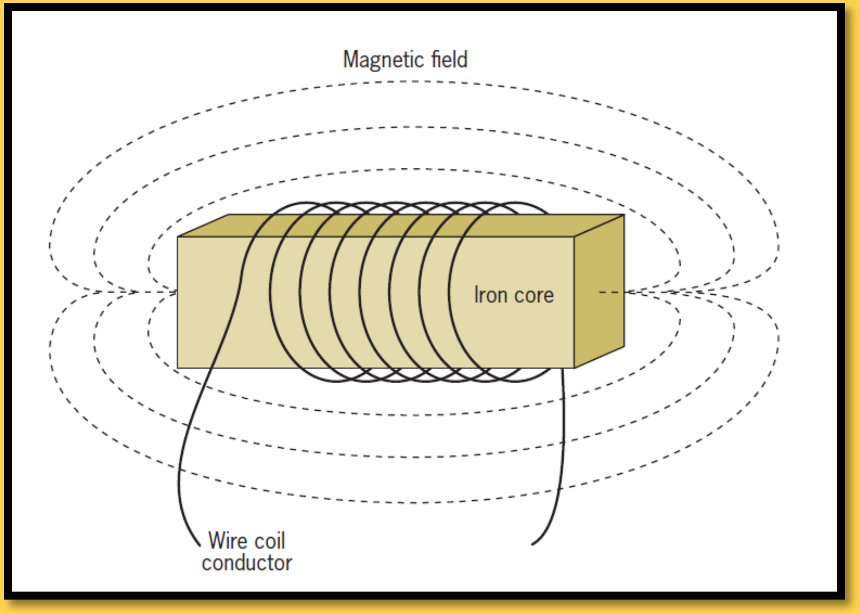
- Relays, contactors and starters are very similar devices that energize a magnetic coil to open or close at set of switches:
  - Relays are 15 amps or less;
  - Contactors are 15 amps or more; and
  - A starter is a contactor with overload protection.
- Number of poles.
- NO or NC.





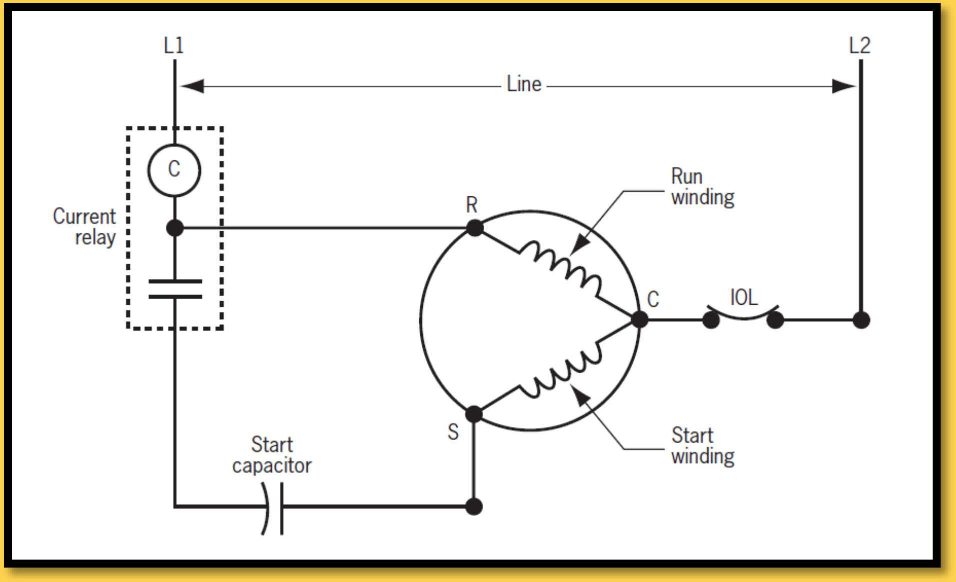
Relay Coil

- Wire wrapped around an iron core.
- Verify condition with an ohmmeter (power off).
- Verify voltage to coil.
- Voltage drop should not be present across closed contacts.



Current Relay

- Smaller systems may make use of this component.
- Contacts remain closed during inrush current.
- Contacts are opened when motor reaches 75% of full running speed.

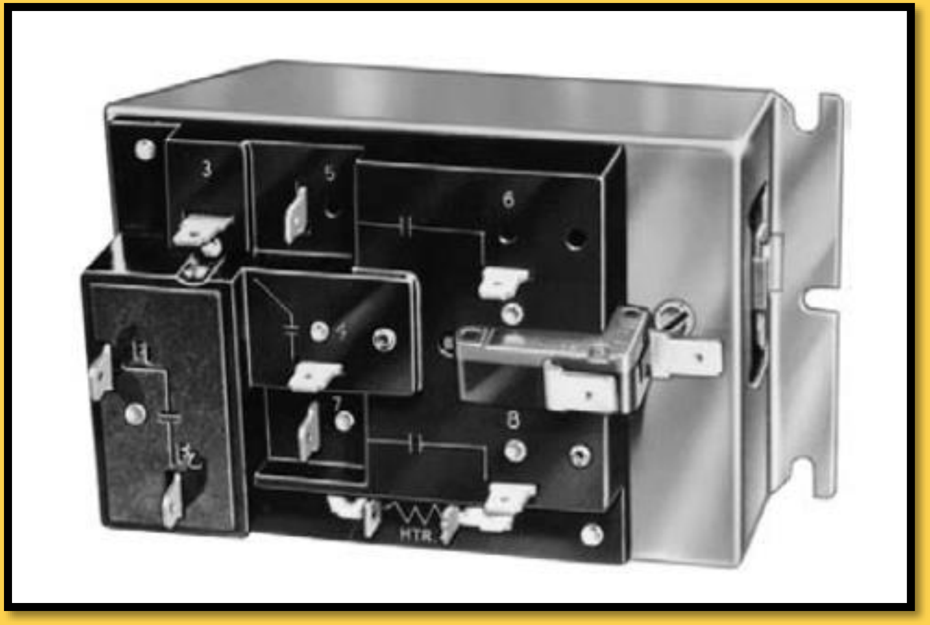


Electronic Control Boards

- Electronic control boards provide switching based on multiple inputs.
- Controls component timing.

Sequencers

- Sequencers provide staging of electric heating elements to reduce the high inrush current that would result from starting them all at once:
  - A specific purpose time delay relay.



Mild-weather Control

- Fan-cycling control designed to reduce the evaporator load and in turn the head pressure during mild weather:
  - Prevents the heat pump from tripping out on high head pressure.

Low Ambient Control

- When cooling needs to operate in ambient conditions below 65°F, the head pressure may drop too low to maintain proper refrigerant flow:
  - Fan cycling often is used to stop the fan if head pressure drops below set point;
  - Fan speed controls also may be used; and
  - Condenser flooding is a non-electrical option.

Capacitors

- A capacitor is a device that has the ability to store an electrical charge.
- The capacitor has two plates separated by dielectric material.
- The capacitor creates a phase shift in the opposite direction as that created by a motor:
  - This correction can improve motor torque and efficiency.

Capacitors

- Microfarad rating – ability to hold a charge.
- Voltage rating – maximum voltage the dielectric can withstand.
- Capacitors can be tested with an ohmmeter :
  - Opens;
  - Shorts; and
  - Grounds.
- Actual microfarad readings must be checked with a capacitance meter.
- A failed capacitor will prevent a motor from starting or cause it to run hot.

Start Capacitor

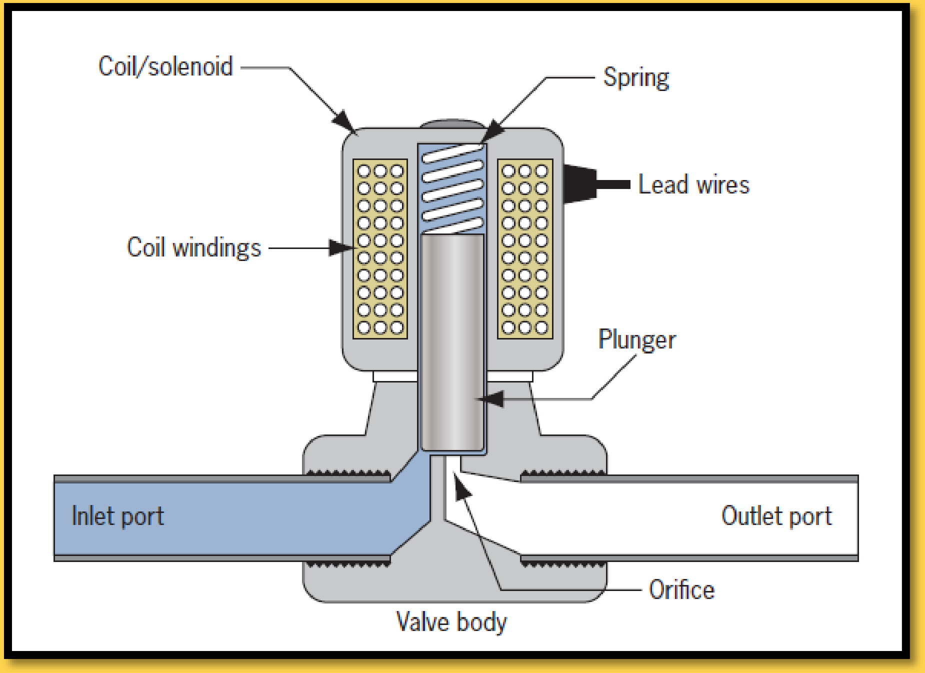
- Designed to stay in the circuit for a short period of time (until motor has reached 70% to 80% running speed).
- 75mfd to 600 mfd.
- No cooling required.
- Primary function is to increase starting torque.

Run Capacitor

- Designed to stay in the circuit during the entire run cycle.
- Will require cooling:
  - Oil is used to dissipate the heat.
- 2mfd to 60mfd.
- Primary function is to improve efficiency.

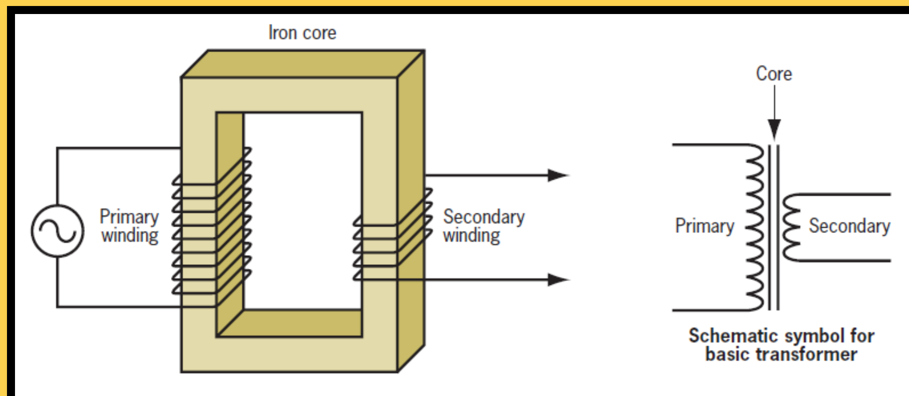
Solenoid valve

- Solenoid valves use a magnetic coil to open or close a valve:
  - NO or NC.
- Reversing valves for heat pumps.
- Pump down system.



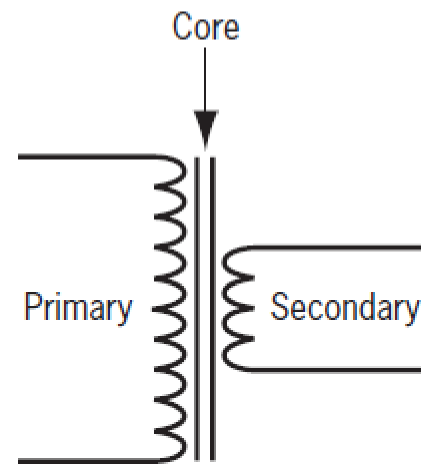
Transformer

- Step up.
- Step down.
- Primary winding.
- Secondary winding:
  - Voltage supplied to the primary induces a voltage into the secondary (no electrical connection).
- Turns ratio.
- Multi tap.
- VA rating.



Transformer

- Specific primary voltage.
- Multi-tap secondary.
- Rated in VA.
- Should be fused.



Schematic symbol for basic transformer

Thermostat

- Temperature controlled switch.
  - Needs to be installed away from:
    - Sunlight;
    - Supply grilles; and
    - Other heat sources.
  - Controls:
    - Compressors;
    - Fans;
    - Heaters; and
    - Reversing valves.

Thermostat Types

- Bimetal.
- Electronic.
- Sensing bulb.
- Low-voltage .
- Line voltage.
- Low ambient.

Bimetal Thermostats

- Two dissimilar metals bonded together that will warp with a change in temperature.
- Wrapped into a spiral to increase the length and amount of movement per degree of temperature change.
- Magnet made be added to provide fast action of the contacts.
- Mercury provides the same function:
  - Mercury stats must be mounted level; and
  - Mercury is a hazardous material.

Anticipators

- Heat anticipators:
  - Connected in series with the heating control device;
  - Energized during a call for heat; and
  - Adjustable.
- Cooling anticipators:
  - Connected in parallel with the cooling thermostat;
  - Energized during the off cycle; and
  - Non-adjustable.

Sensing Bulb

- A gas-filled bulb.
- Pressure increases or decreases with a change in temperature.
- Pressure works against a bellows to open or close a switch.
- Generally used in outdoor applications.

Electronic

- Microprocessor based controls that use thermistors to sense temperature:
  - PTC or NTC.
- Electronic thermostats often need a common connection to provide 24 V to operate.
- Programmable:
  - 7 day; and
  - 5/2 day.
- Intelligent recovery.

Line Voltage

- Line-voltage thermostats directly switch 115-V or 208-V/230-V loads.

Low Ambient

- Low-ambient controls are used to lock out equipment when the temperature drops below the setpoint.

Crankcase Heaters

- Crankcase heaters:
  - Strap-on or belly band;
  - Insertion-type; and
  - Motor winding.

Resistive Heat

- Electric furnace.
- Auxiliary heat.
- Emergency heat.
- Heater must be de-rated if a lower voltage is applied.
- Proper airflow is critical:
  - High-limit switches; and
  - Fusible links.
- 60 A maximum overcurrent protection.

Defrost Controls

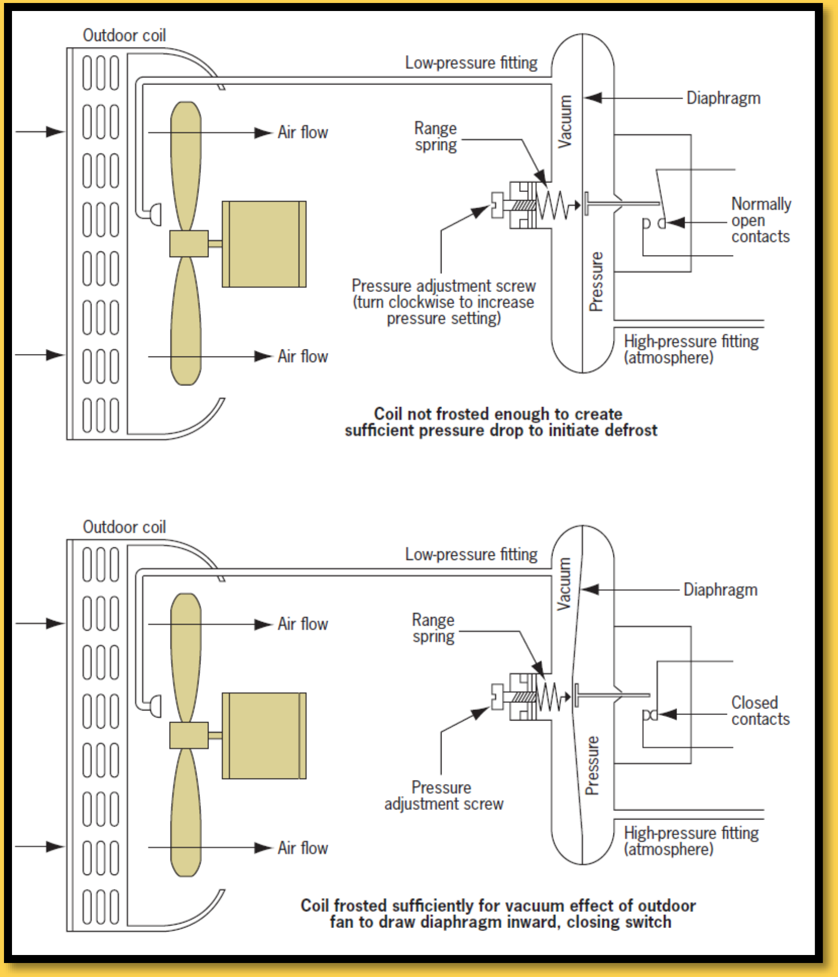
- Air-to-air heat pumps will require defrost cycles due to the low operating temperatures during the heating mode.
- Defrost must be initiated when airflow through the outdoor coil is reduced to about 50%.
- Up to four events take place simultaneously when defrost begins:
  – The reversing valve is switched to operate in the cooling mode;
  – The outdoor fan motor is switched off;
  – The auxiliary heat is turned on; *and*
  – Gas furnace may be cycled on and off.

Defrost Cycle

- Initiated and/or terminated by:
  - Time;
  - Temperature; and/or
  - Air pressure.
- Defrost regulation:
  - Mechanical defrost timer sets time to check for defrost requirement (i.e., liquid-line thermostat); and
  - Time *and* temperature must be satisfied.

Defrost Cycle

- Pressure switches may be used rather than thermostats.
- Solid-state controls may be used.
- Outdoor air and outdoor coil temperature are measured to determine if defrost is required.



Summary

- Electricity drives mechanical components.
- Electrical circuits direct the flow of current.
- Technicians must understand basic principles.
- Electrical components must be respected.
- Only qualified, trained individuals should be allowed to service HVACR systems.

Installation Guidelines

Chapter 5

Lesson Objectives

- Proper pre-installation calculation and design.
- Components.
- Installation and setup.
- Safety.

Installation

- 90% of new systems have inadequate ductwork. Many of these systems are:
  - Undersized;
  - Improperly sealed; and/or
  - Have undersized returns.

Air Flow

- Proper airflow to the indoor coil is critical.
  - Low airflow:
    - Lower suction temperature and reduced efficiency;
    - Icing of the coils; and
    - Liquid carry over.
  - High airflow:
    - Poor humidity control.

Air Leakage

- Supply air not getting to where you need it.
- Additional unconditioned air being drawn into the system.

Indoor Section

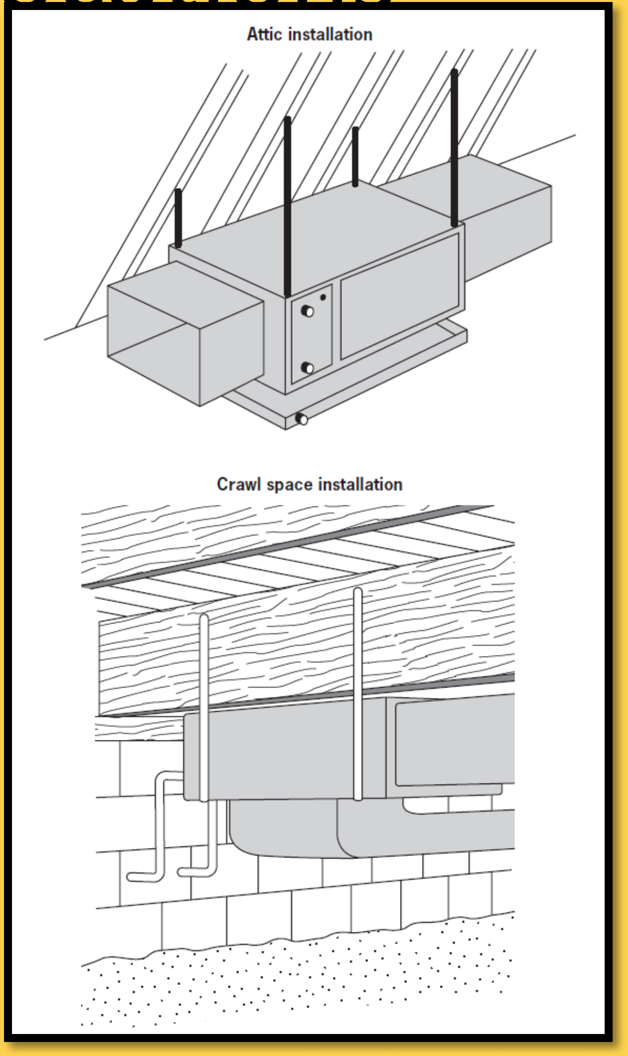
- Air handler for cooling only.
- Electric furnace.
- Fossil-fuel furnace:
  - Coil added for cooling; and
  - Heat -pump coil will serve as an evaporator for cooling and as a condenser for heating.

Indoor Section Installation Preparation

- Carefully check for shipping damage.
- Check for missing components.
- Do not use during construction.
- Architect, contractor, homeowner select location:
  - Must have the required clearances as stated in the installation instructions.

Possible Locations

- Basement.
- Crawlspace.
- Attic.
- Utility room.
- Closet.
- Alcove.
- Garage.

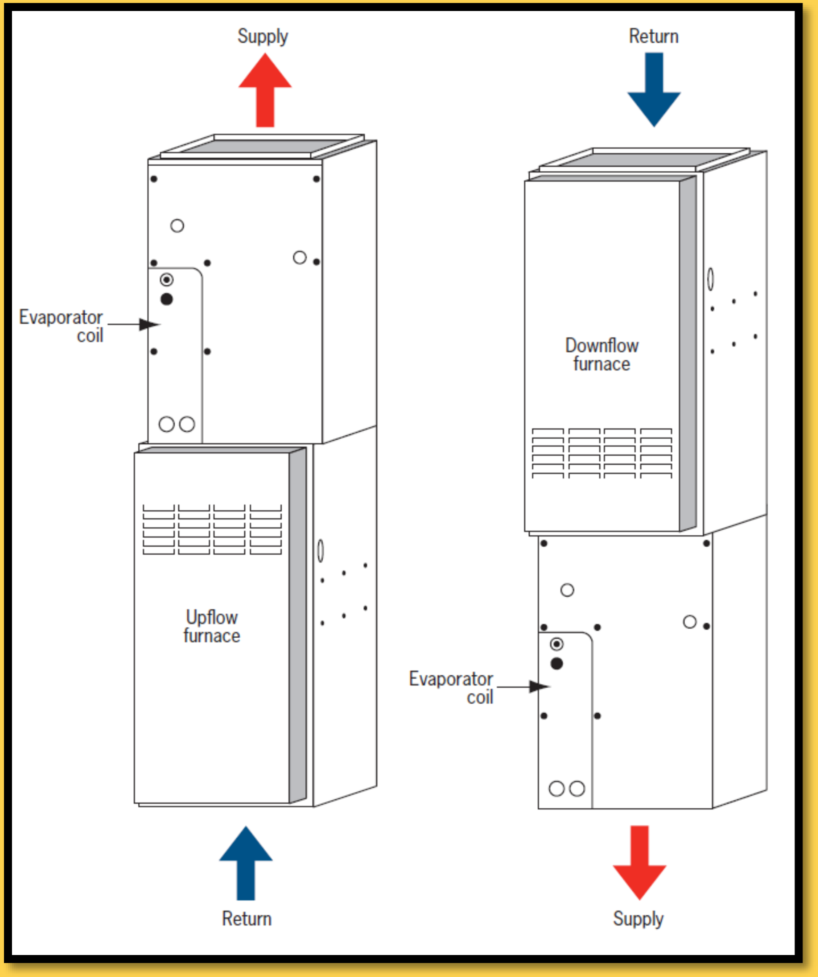


Sound Transmission

- Structural Isolation:
  - Pads;
  - Springs; and/or
  - Concrete.
- Flexible duct connectors.
- Piping isolation.

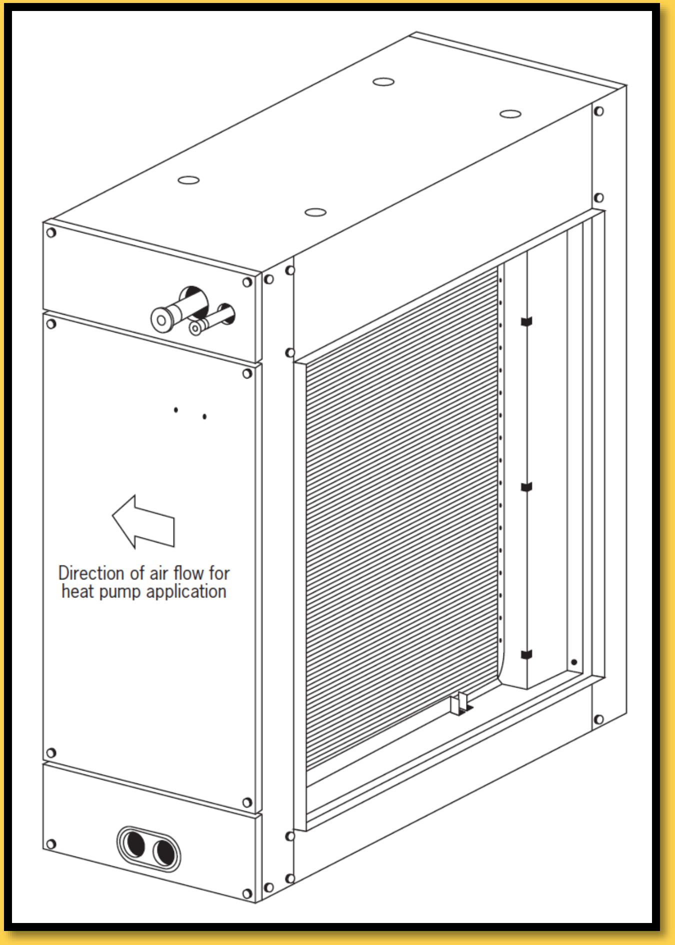
Configurations

- Upflow.
- Downflow or counterflow.
- Horizontal.
- Low boy.



Evaporator Coil

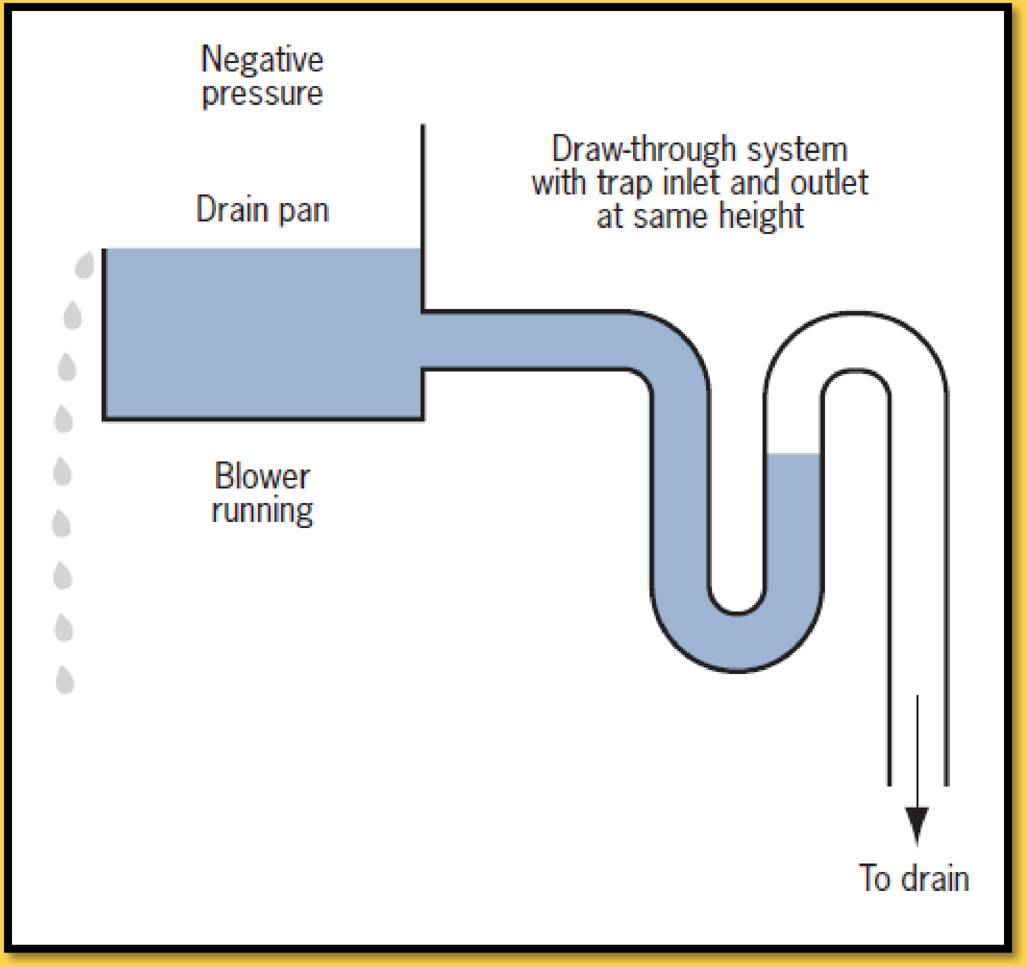
- Removes water vapor in the air that must be drained.
- Condensate piping is run to indoor drain or dry well outside.
- Condensate drain must be properly trapped.



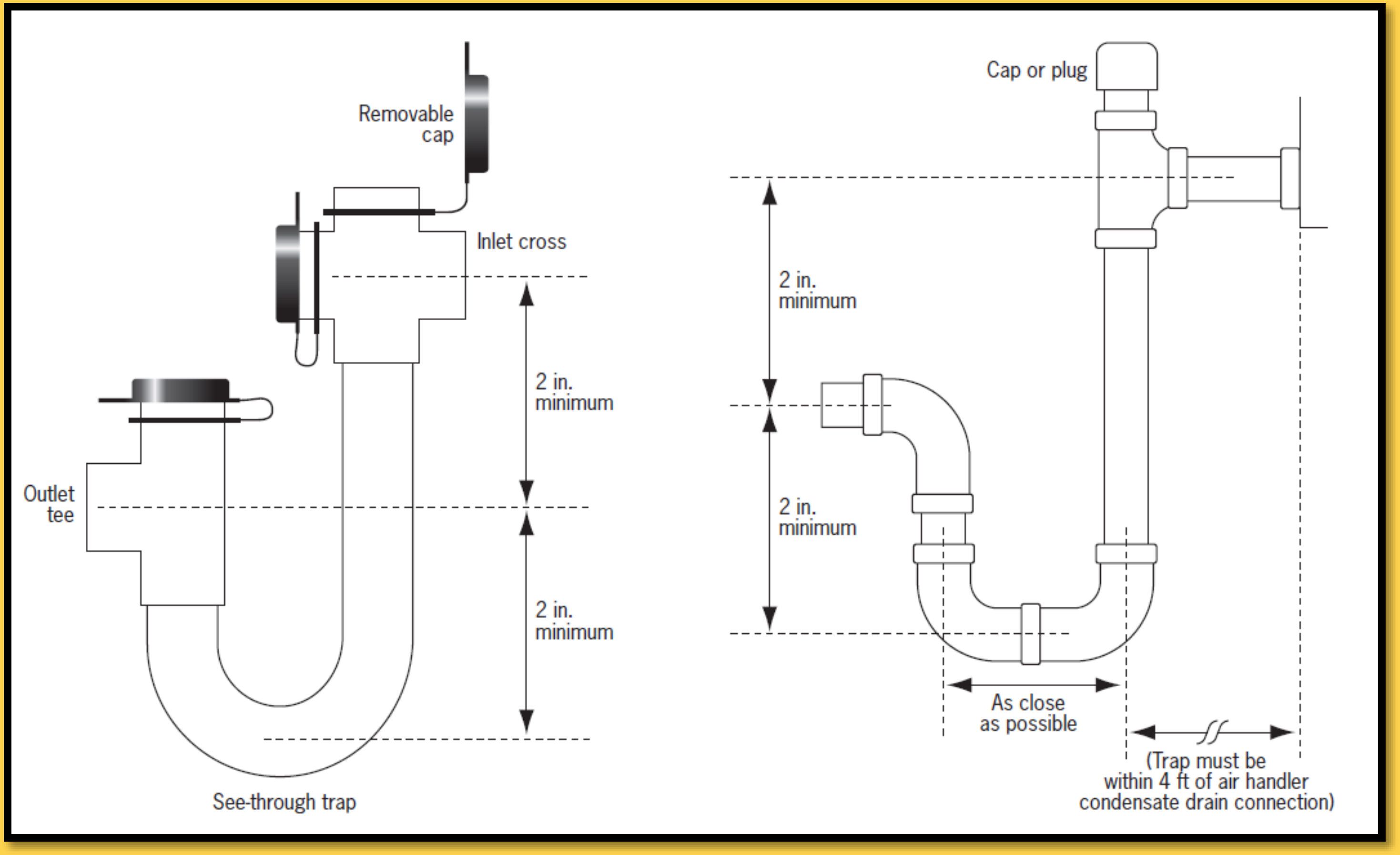
Condensate

- Condensate from the evaporator coils must be piped to a drain or a dry well:
  - An air gap must be provided to prevent sewer gas from backing up into the condensate drain.
  - The condensate drain must be trapped to:
    - Allow for proper drainage on a draw through coil; and
    - To prevent air from being blown through the drain on a blow through coil.
- The outlet of the trap must be lower than the inlet (twice the static of the blower).

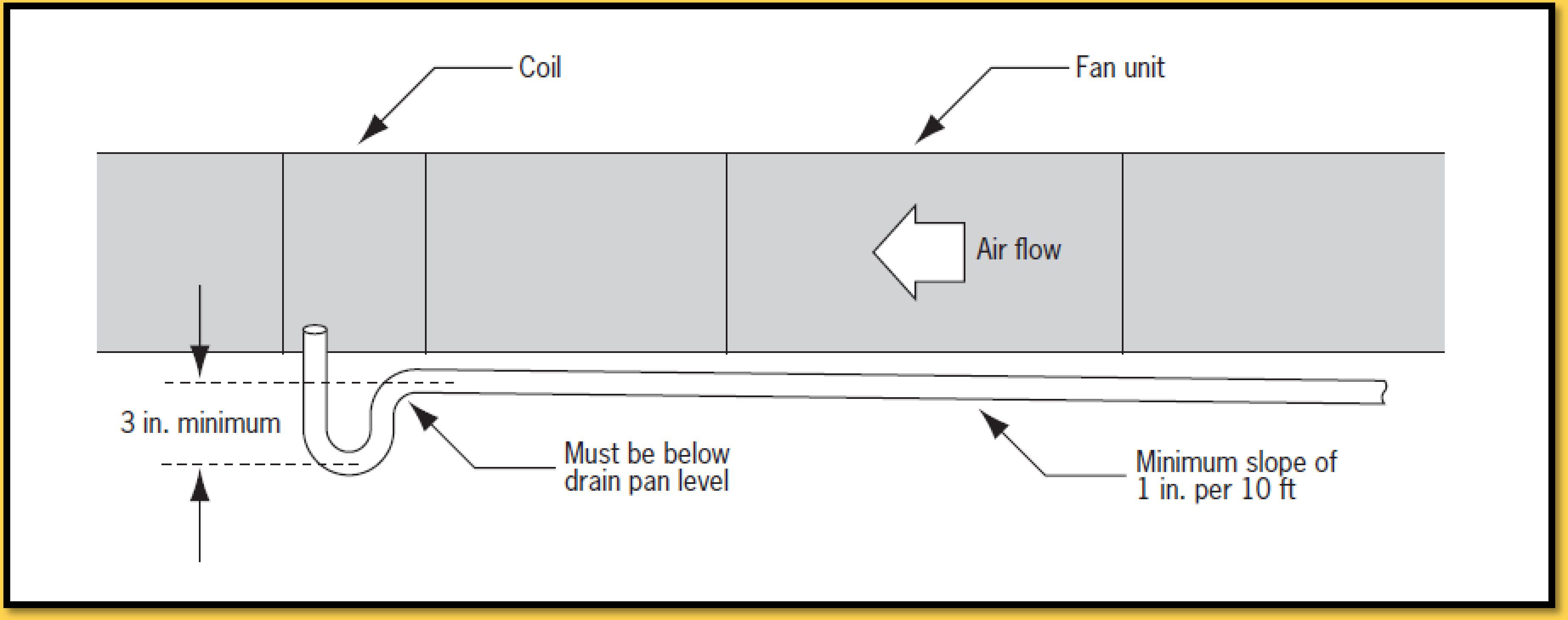
Running Condensate Trap



Condensate Trap Styles (Manufactured and Fabricated)

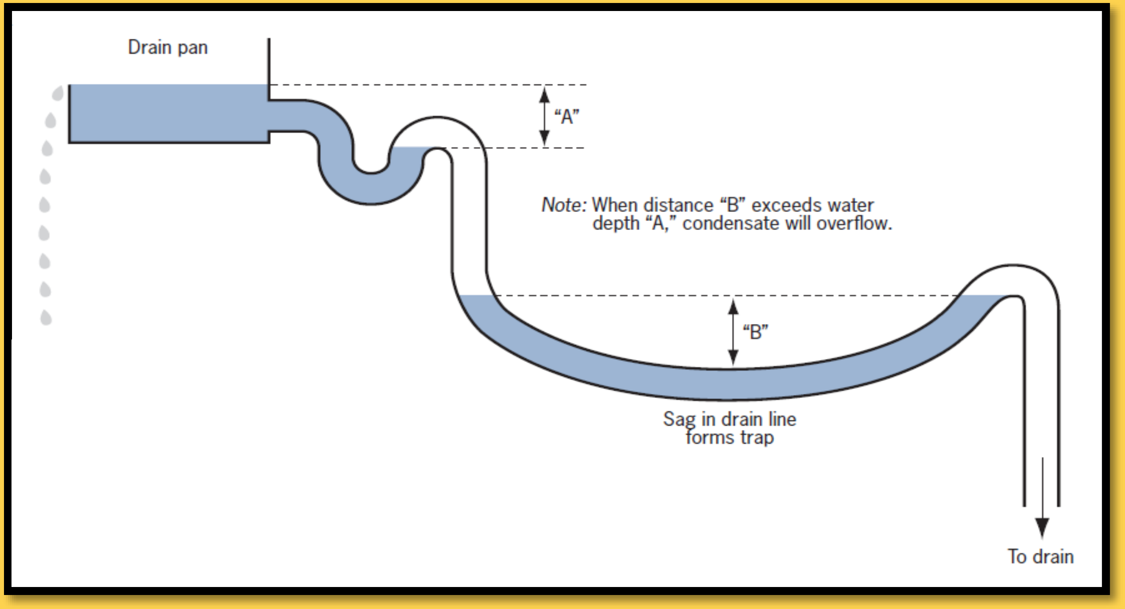


P-trap and Sloping Drain Line



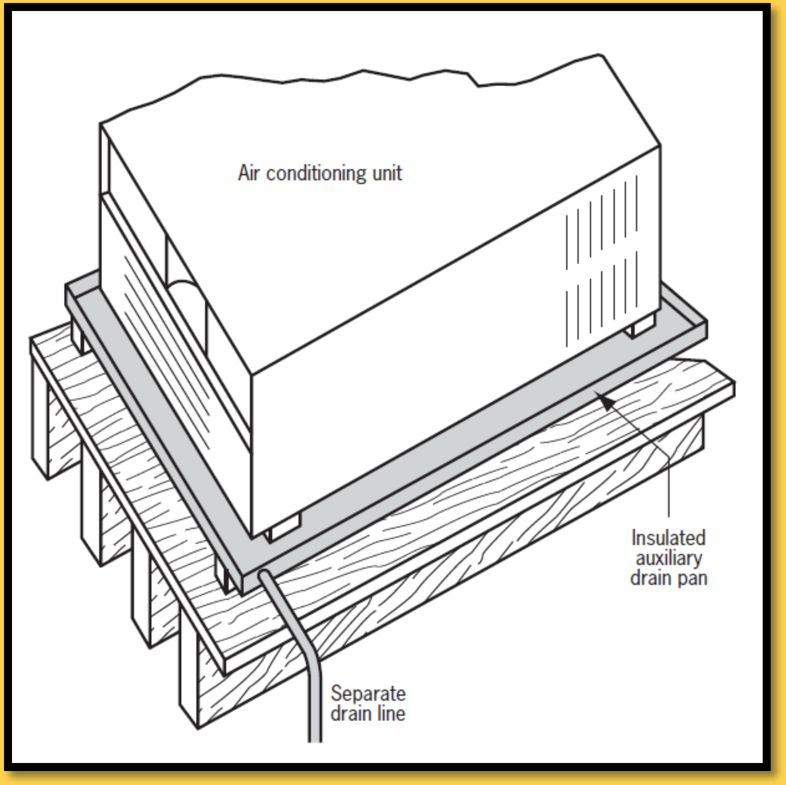
Improper (Sagging) Drain Line

- Air is trapped between water pockets.
- Water overflows the condensate drain pan.



Attic Installations

- Condensate drains and drain pans for attic units should be insulated to prevent condensation from forming on the outside of them
- A secondary drain pan should be installed and drained to a location that will be readily noticed



Ductwork

- Ductwork must be designed to deliver the needed air within the available static pressure drop of the blower.
- 400 cfm to 450 cfm per ton.
- External static pressure:
  - Typically 0.5 in. w.g. for residential units.
- Supply ducts should be sized for 0.1 in.
- Return ducts should be sized for 0.08 in.

Airflow and ESP

- Manufacturer's charts illustrate blower performance data at various ESP values.
- Excessive resistance results in less airflow than needed.

Air flow, cfm	External static pressure (in. w.g.)											
	Vertical*						Horizontal**					
	230 V			208 V			230 V			208 V		
	HI	MED	LO	HI	MED	LO	HI	MED	LO	HI	MED	LO
500						0.55						
550						0.51						0.60
600					0.67	0.41						0.58
650			0.54		0.60	0.23			0.60			0.51
700			0.53		0.52	0.00			0.57		0.51	0.47
750		0.48	0.44	0.65	0.41			0.54	0.53		0.48	0.35
800	0.52	0.47	0.27	0.59	0.30		0.60	0.52	0.46	0.59	0.41	0.05
850	0.50	0.41	0.00	0.52	0.10		0.57	0.47	0.32	0.55	0.32	
900	0.47	0.30		0.42	0.01		0.54	0.40	0.03	0.52	0.21	
950	0.41	0.15		0.29			0.49	0.31		0.45	02	
1000	0.33	0.00		0.14			0.41	0.19		0.33		
1050	0.22			0.00			0.32	0.04		0.19		
1100	0.10						0.23			0.00		
1150	0.00						0.12					
1200							0.02					

* Vertical installation: With filter, no horizontal drip tray. Small apex baffle. Subtract 0.06 in. w.g. for downflow.
** Horizontal installation: As shipped, but without filter. Subtract 0.05 in. w.g. for horizontal left.

Design

- ACCA *Manual J*
  – *Residential Load Calculation*
- ACCA *Manual D*
  – *Residential Duct Systems*
- ACCA *Manual N*
  – *Commercial Load Calculation*
- ACCA *Manual Q*
  – *Commercial Duct Systems*

Ductwork

- All joints must be seal with approved tapes or mastics.
- Proper insulation and vapor barrier must be installed to prevent condensation and heat transfer.

Ductwork

- Electric duct heaters must be at least 4 ft from the air handler.
- Fire dampers are installed where ducts pass through fire walls:
  - Static – closes under low air flow (gravity).
  - Dynamic – closes under positive air flow (spring).

Fire Dampers

- Two types:
  - Static:
    - Very little or no airflow when damper closes.
  - Dynamic:
    - Fan pressure will be present during a fire;
    - Designed to close against air velocity and pressure;
    - Used in commercial applications; and
    - Fusible link melts and closes the damper in a fire.

Duct Support

- Duct hangers must be installed at regular intervals to prevent stress and sagging.
- Duct supports must not create a thermal bridge.

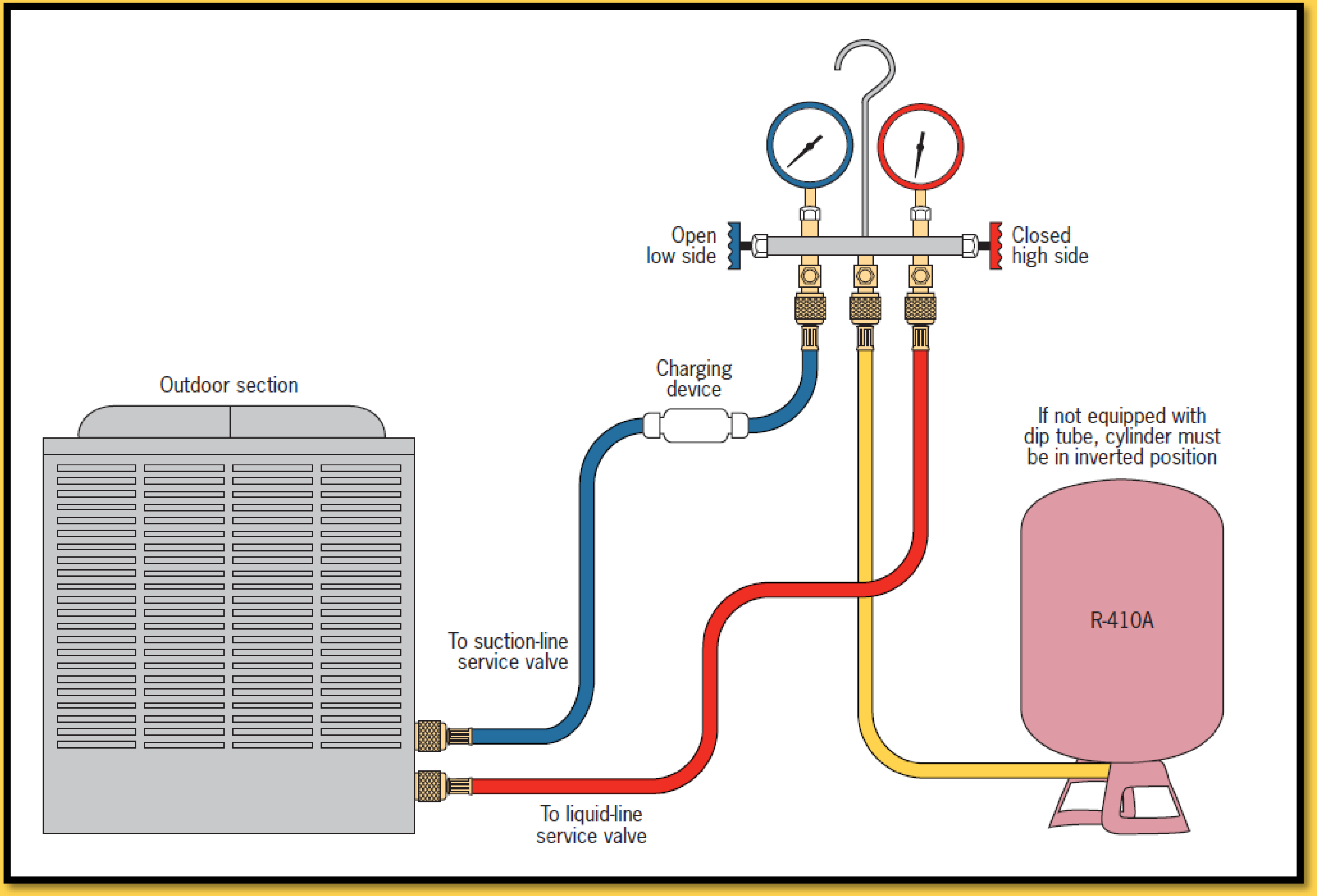
Outdoor Section

- Check for transportation damage:
  - Report any damage to supervisor.
- Refer to nameplate for voltage requirements:
  - Incorrect voltage can damage electrical components.

Refrigerant

- Many existing R-22 units:
  - Not available charged with R-22 starting in 2010.
- New units are using R-410A:
  - POE oil:
    - Keep system sealed (hygroscopic).
  - 50%–70% higher pressure than R-22;
  - Charge from the cylinder as liquid:
    - Technique illustrated on the next slide.
  - Change driers when system is opened for repairs.

R-410A Charging



Outdoor Unit Location

- Away from building or plants (1 ft – 2 ft).
- Clear space above unit (5 ft).
- Elevated above snow line and drifts.
- Allow for condensate drainage.
- Not under a window.
- Avoid drainage from the roof.
- Away from dryer and kitchen vents.
- Solid, level pad.

Refrigerant Piping

- ACR tubing only.
- Purge with nitrogen while brazing.
- Proper filler and flux must be used.

Brazing

- A form of welding.
- Heats base metals above 700°F.
- Brazing alloys and flux are used.
- Industrial gases are used to braze tubing:
  - Example: Oxyacetylene; and
  - DOT regulations apply.

Proper Gas-handling Procedures

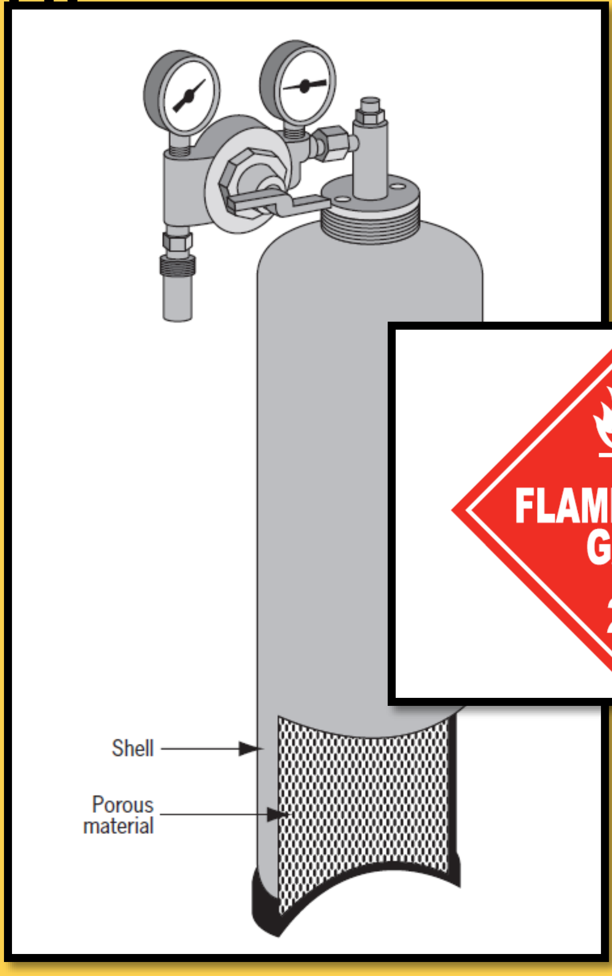
- DOT regulate transportation of cylinders.
- Always properly secure cylinders.
- Cap cylinders when not in use.
- Close valves completely and mark empty cylinders.
- Do not use unidentified cylinders.
- Wear appropriate PPE.

Oxygen

- Required to support the burning process.
- Cylinders pressurized at 2000 psi+.
- Never allow pure oxygen to come in contact with oil or grease.
- Never stand in front of the regulator when opening the valve on the tank.
- Open valve 100 % to seal packing.

Acetylene

- Acetylene is absorbed into acetone within the cylinder:
  - Always keep cylinder upright.
- Only authorized gas distributors should refill acetylene cylinders.
- Flammable gasses such as acetylene will have a HAZMAT sign on the tank.



Pressure Regulator

- Reduce pressure to low working pressures for brazing.
- Includes a relief valve.

Opening Cylinder Valves

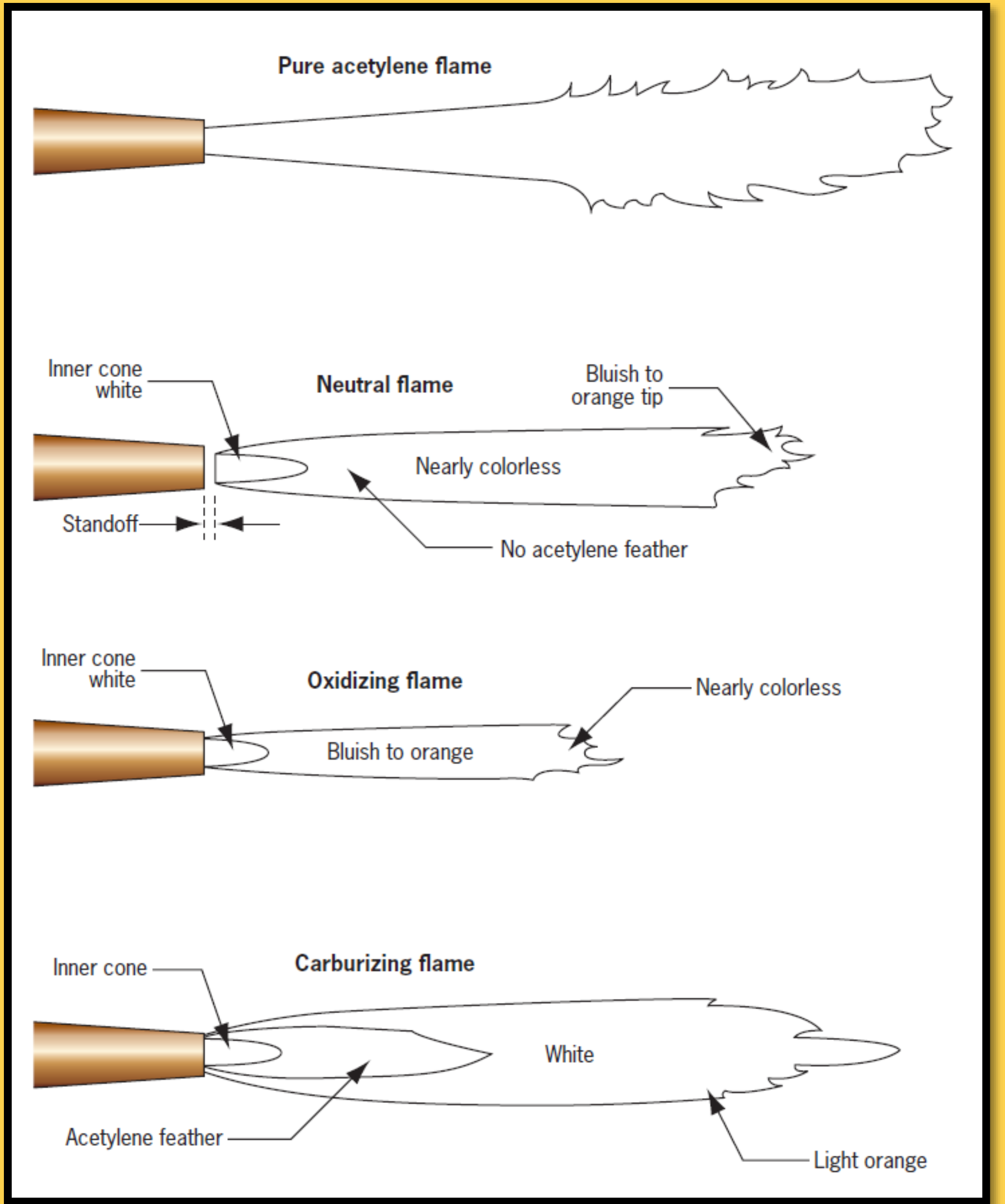
- Follow directions for opening valves and use caution.
- Open tank no more than 1½ turns.
- Use of back-flash arrestors is highly recommended .

Welding Hose

- Transports low-pressure gases from the regulator to the torch.
- Oxygen hose: green.
- Fuel hose: red.
- Marked with grade.

Brazing

- Oxyacetylene is commonly used for brazing.
- Always clean joint before brazing.
- Base metals must be properly heated.
- Flux must be used if brazing copper to some other metal.
- Always purge with nitrogen.
- Always use a neutral flame.



Completion of Brazing

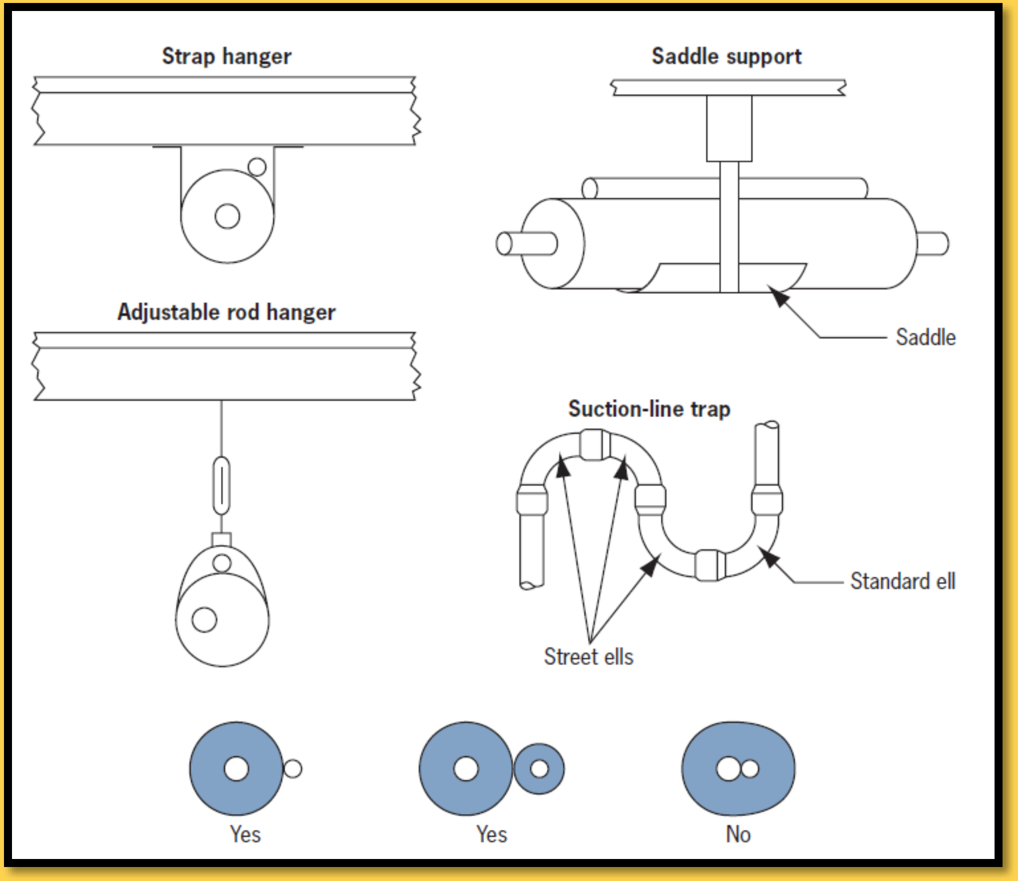
- First shut off the torch oxygen valve, then shut off the torch fuel valve:
  – If this procedure is reversed, a “pop” may occur.
- Close both cylinder valves.
- Open torch oxygen valve, let oxygen in system drain out. Close torch oxygen valve.
- Turn adjusting screw on oxygen regulator counterclockwise to release all spring pressure.
- Check both oxygen and fuel high-pressure gauges after a few minutes to ensure that the cylinder valves are turned completely off.

Refrigerant Piping

- Use long radius elbows.
- Use spring or lever benders to bend soft drawn tubing.
- Install traps as recommended.
- Insulate suction lines.
- Insulate liquid lines in high-temperature environments.

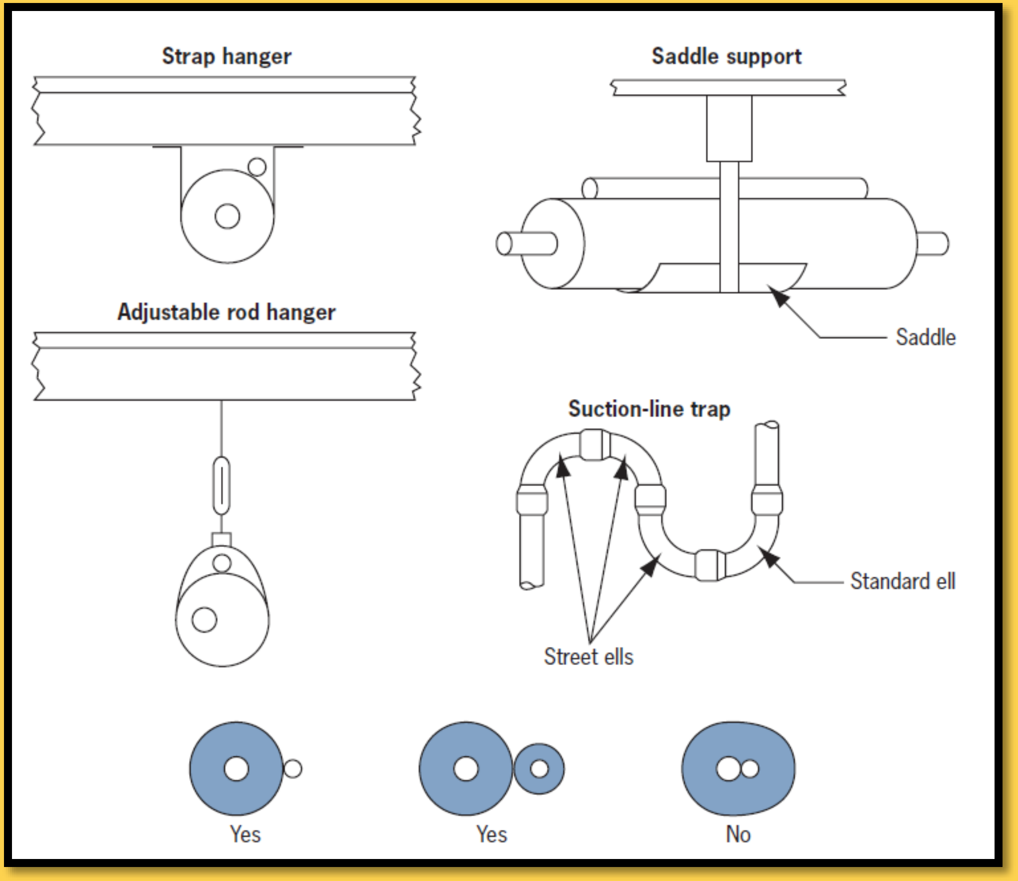
Refrigerant Piping Hints

- Determine the most practical way to run the lines.
- Consider the types of bends made while allowing for space limitations.
- Determine the best starting point inside or outside the structure..
- Provide a pull-through hole of sufficient size.



Refrigerant Piping Hints

- Make sure that the tubing is of sufficient length.
- Uncoil the tubing while taking care not to kink or dent it.
- Route the tubing, making all required bends, and properly secure the tubing before making connections.

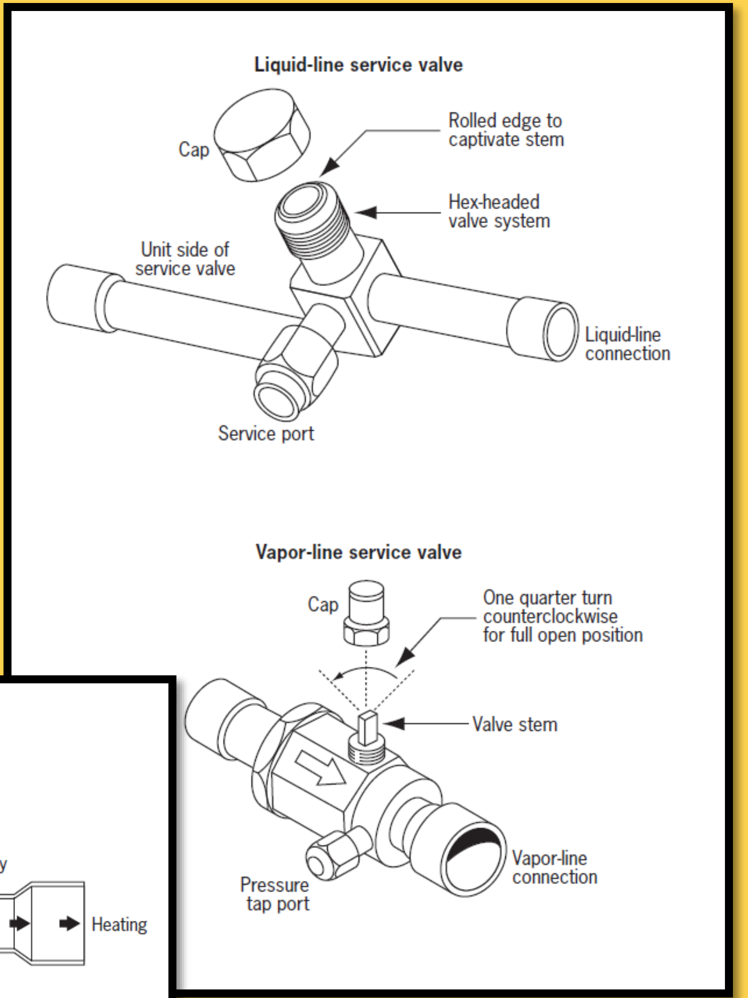


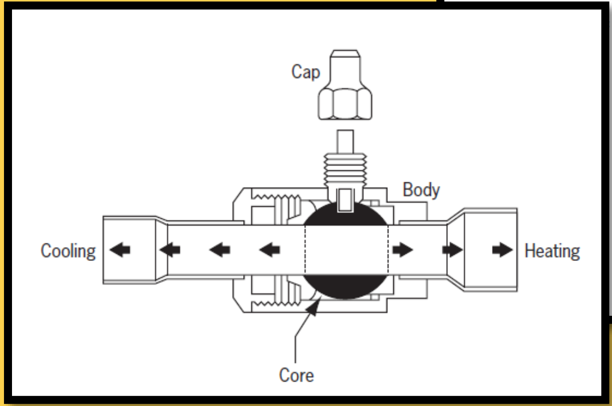
Preventing Vibration Transmission

- Use isolation-type hangers when fastening lines to floor joists or other framing in a structure.
- Use isolation-type hangers when lines are run in stud spaces or enclosed ceilings.
- Where refrigerant lines run inside a wall or through a sill, they must be isolated and well-insulated with glued joints.
- Refrigerant lines must be isolated from all ductwork.

Service Valves

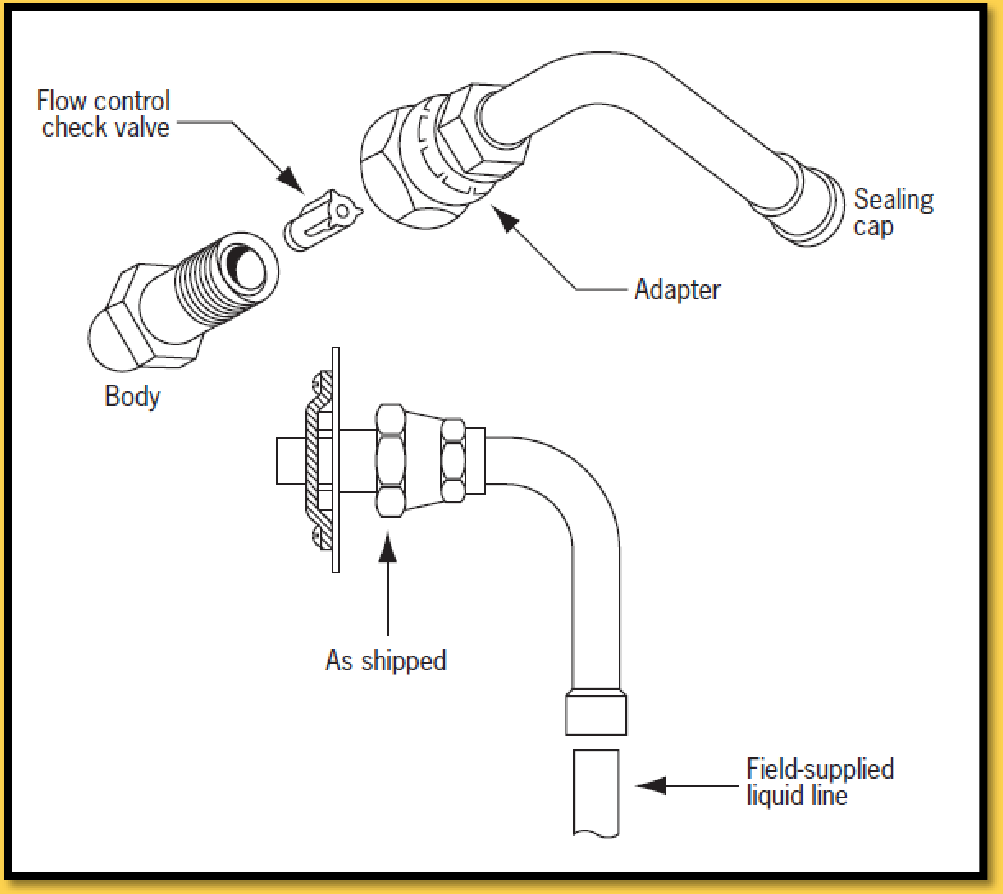
- Installed on pre-charged outdoor units.
- Remove valve cores before brazing and protect valves from overheating.
- Open valves only to the stop do not over turn.
- Ball valves fully open with a ¼ turn connect the vapor line to the outdoor section.





Metering Device

- TXV/TEV.
- Pistons:
  - Make sure the installed piston matches the outdoor unit.



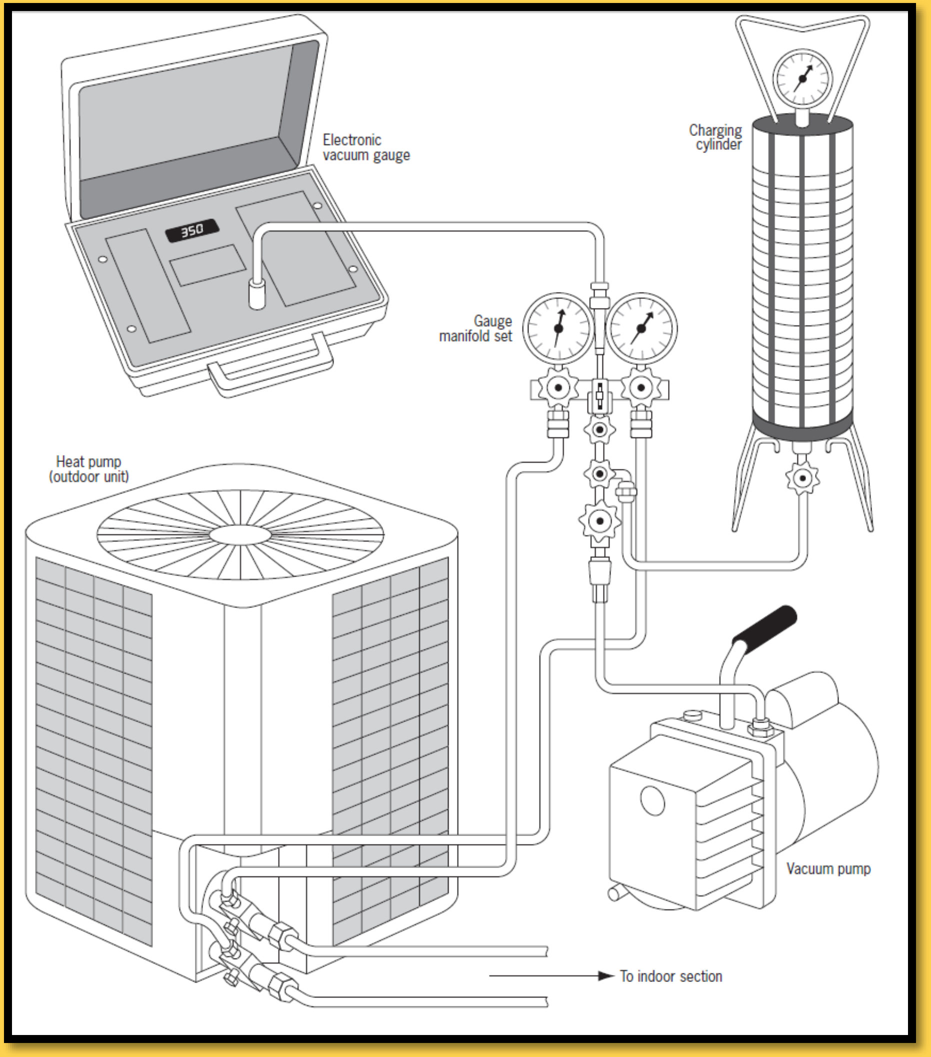
Leak Test

- After brazing is complete the unit should be leak tested.
- Pressurize with nitrogen and check joints with soap bubbles.

Evacuation

- Connect hoses to both the liquid and suction side of the system.
- Evacuate to 350 microns.
- Close off valve to the pump:
  - Pressure should not rise above 500 microns.
- Open isolation valves or add refrigerant.
- Adjust charge as needed for line length.

Typical Evacuation / Charging Connection Procedures



Electrical Connections

- Ensure proper grounding.
- Check voltage with nameplate.
- Maximum over-current protection on electric heaters 60 A (48 A max load).
- Disconnect within sight.
- Flexible conduit for vibration.
- Disconnect power before working on the unit.
- Follow field wiring diagrams from manufacturer.

Low Voltage

- Color code wires.
- Be aware of wire size and length to prevent voltage drop:
  - 18 AWG common for residential applications.
- Do not install low voltage in conduit with line voltage.

Wire size	Maximum wire length
18 AWG	150 ft
16 AWG	225 ft
14 AWG	300 ft

Thermostat Location

- Mount level.
- Away from drafts.
- Out of direct sunlight.
- Away from heat sources.
- Away from supply air outlets.

Before Start-up

- Make sure all packing has been removed.
- Ensure fans and blowers spin free (power off).
- Check wire connections.
- Check valve positions.
- Energize the crankcase heater.

Outdoor Thermostat: Heat Pumps

- Controls stages of auxiliary heat.
- Prevents auxiliary heat until the thermal balance point is reached.

Variable Capacity

- Two-stage compressors.
- Two-speed compressors.
- Variable-speed compressors.

Voltage Check

- No load voltage:
  - ± 10% of the nameplate rating.
- Start-up voltage:
  - No more than a 10% drop.
- Full-load voltage:
  - No more than 2% drop.

Current

- Measure amp draw on all motors:
  - Compressor.
  - Indoor blower.
  - Condenser fan.
- Compare to RLA or FLA ratings.

Electric Heat

- Check minimum circuit requirements.
- Sequencers.
- Blower delay:
  - Heating.
  - Cooling.

Other Component Check

- Indoor blower "off delay."
  - Reduces condensation and opportunity for biological material growth on the indoor coil.

Component Check: Defrost Controls

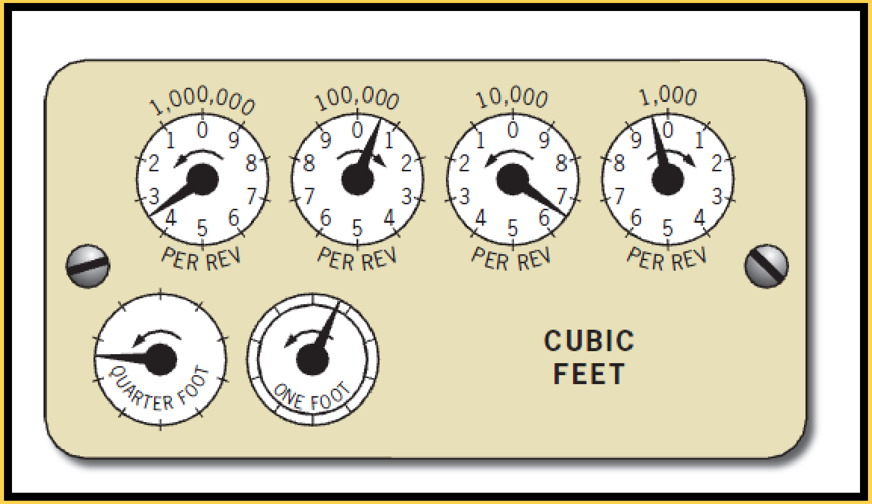
- Initiation:
  - Timed.
  - Two-temperature.
  - Pressure.
- Termination:
  - Timed.
  - Temperature.
- Verify proper operation.
- Use manufacturer's recommended test procedures.

Component Check: Auxiliary Devices

- Electronic air cleaner.
- Humidifiers.
- Verify proper voltage and operation.

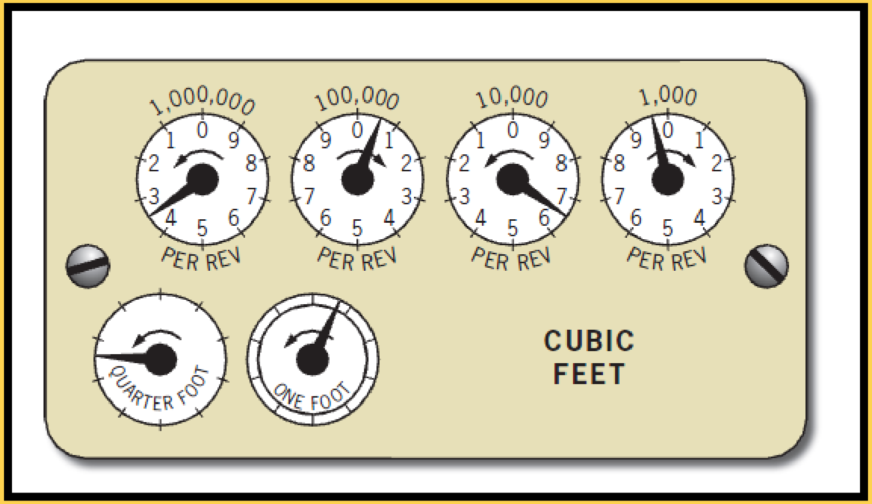
Airflow: Gas Furnace

- Determining cfm produced by a gas furnace.
- Clock the gas meter to determine the Btuh input to the furnace:
  – Determine the seconds to consume 1 ft³.



Gas-meter Clocking Example

- Heating value of 1 ft^3 of gas: 1,000 Btu/ft^3.
- Time to consume 1 ft^3 of gas: 46 seconds.
- 1,000 x (3600 sec/hr ÷ 46) = 78,260 Btuh input.
- Output = input x % of combustion efficiency.
- 78,260 $\times$.80 = 62,608.
- Output = 62,608 Btuh.



Airflow: Gas Furnace

- Determine cfm:
  - Calculate Btuh output.
  - Measure the temperature rise (TD).
- Cfm = Btuh ÷1.08 X TD.

$$\text{cfm} = \frac{\text{Btuh}}{1.08 \times \text{TD}}$$

$$= \frac{62{,}608\ \text{Btuh}}{1.08 \times 45\,^{\circ}\text{F}}$$

$$= 1{,}288\ \text{cfm}$$

Airflow: Electric Furnace

- Determine cfm.
- Measure voltage and current draw to indoor section.
- Voltage x current = watts.
- Watts x 3.413 = input.
- Use the following formula:
  - Cfm = Btuh ÷ (1.08 X TD).

$$\text{cfm} = \frac{\text{Btuh}}{1.08 \times \text{TD}}$$

$$= \frac{34{,}540\ \text{Btuh}}{1.08 \times 26^\circ\text{F}}$$

$$= 1{,}230\ \text{cfm}$$

Summary

- Quality design and installation is important:
  - Load calculation, duct design and airflow setup are critical.
- Safety is very important.

Reading Electrical Schematics

Chapter 6

Lesson Objectives

- Understand various schematic types.
- Trace through sequence of operation using ladder diagrams:
  - Heating, cooling and defrost cycles.

Introduction

- One of the largest single influences on our daily lives is electricity.
- Electricity affects each of us in hundreds of ways every day.
- All heating and cooling equipment utilizes electricity.
- Technicians must understand the principles of electricity.
- One of the most important skills that you must have is the ability to read electrical schematics.

Electrical Schematics

- Electricity is a large part of the HVACR technicians job.
- Electrical schematics provide a road map through the electrical systems:
  - Sequence of operation.
  - Location of components.
  - Function of components.

Wiring Diagram Types

- Pictorial.
- Point-to-point.
- Ladder.
- Many manufacturers will use some combination of the three.

Fundamental Principles

1. Electricity always follows the path of least resistance.
2. An electric circuit must have a *power source.*
3. An electric circuit must have a *load* (some device that consumes electric power).
4. An electric circuit must have a *path* from the power source to the load and back to the power source.

Fundamental Principles

5. There is almost always only one load per circuit.
6. There is almost always only one control switch per load.
7. When used, safety switches must be connected in series to protect the load.
8. Electrical schematics are shown with the circuits de-energized, unless otherwise stated.

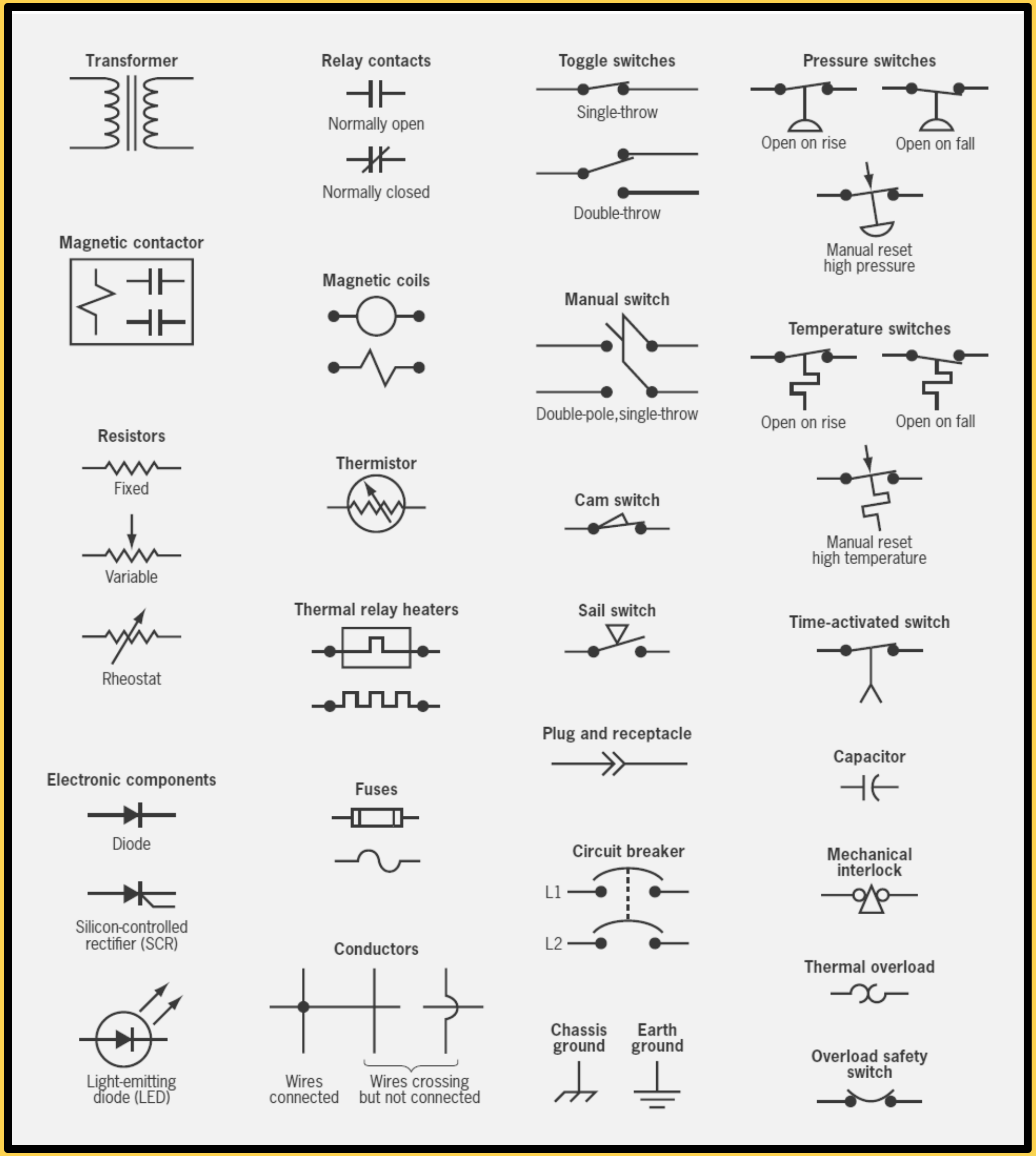
Fundamental Principles

- Electricity follows the path of least resistance.
- A circuit must have a power source, load and path.
- 1 Load per circuit (parallel).
- In most cases – one switch per load.
- Safety switches connect in series.
- Schematics are shown de-energized.

Symbols

- Power-passing devices:
  - Switches.
  - Wires.
- Power-consuming devices – Loads:
  - Inductive – motors and coils.
  - Resistive – heaters.
- Circuit boards (terminals).
- See next slide.

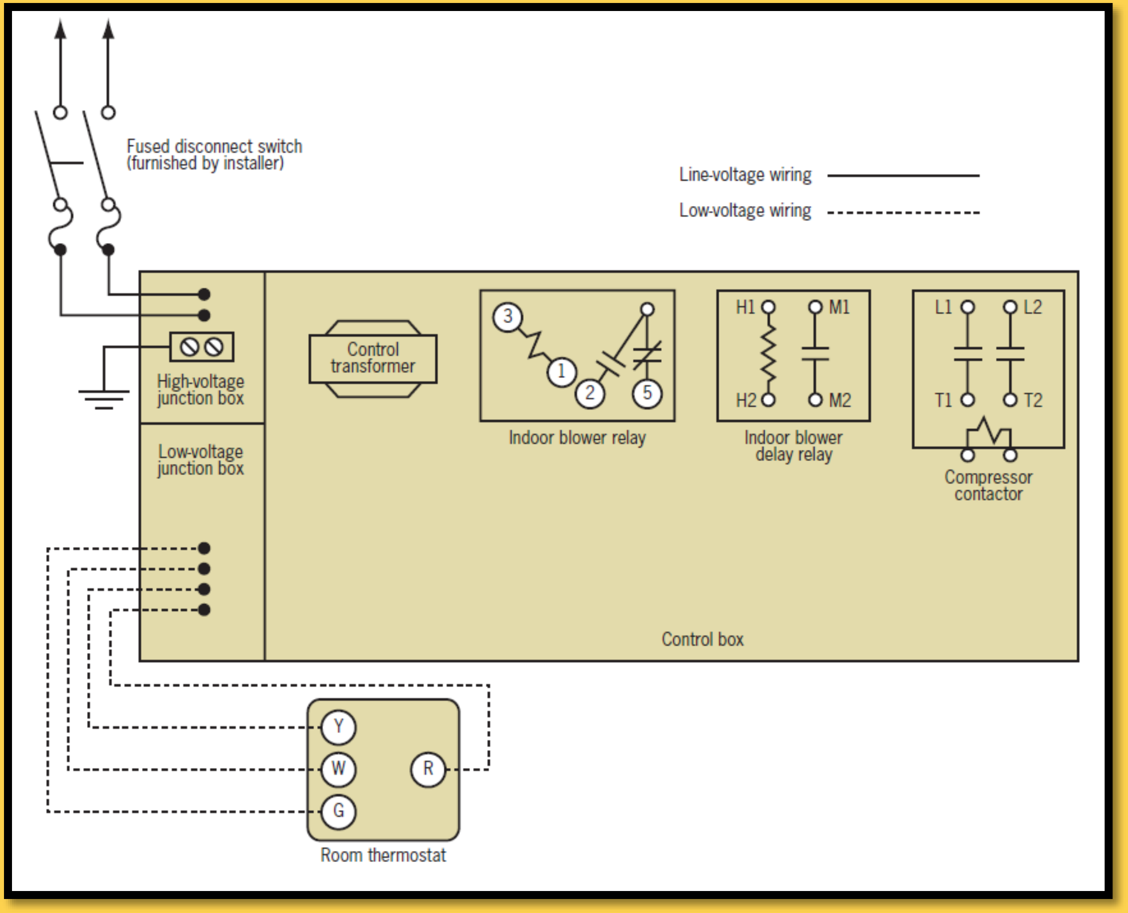
Symbols



Transformer
Relay contacts
Normally open
Normally closed
Toggle switches
Single-throw
Double-throw
Pressure switches
Open on rise
Open on fall
Manual reset high pressure
Magnetic contactor
Magnetic coils
Manual switch
Double-pole, single-throw
Temperature switches
Open on rise
Open on fall
Manual reset high temperature
Resistors
Fixed
Variable
Rheostat
Thermistor
Cam switch
Thermal relay heaters
Sail switch
Time-activated switch
Plug and receptacle
Capacitor
Electronic components
Diode
Silicon-controlled rectifier (SCR)
Light-emitting diode (LED)
Fuses
Circuit breaker
L1
L2
Mechanical interlock
Thermal overload
Conductors
Wires connected
Wires crossing but not connected
Chassis ground
Earth ground
Overload safety switch

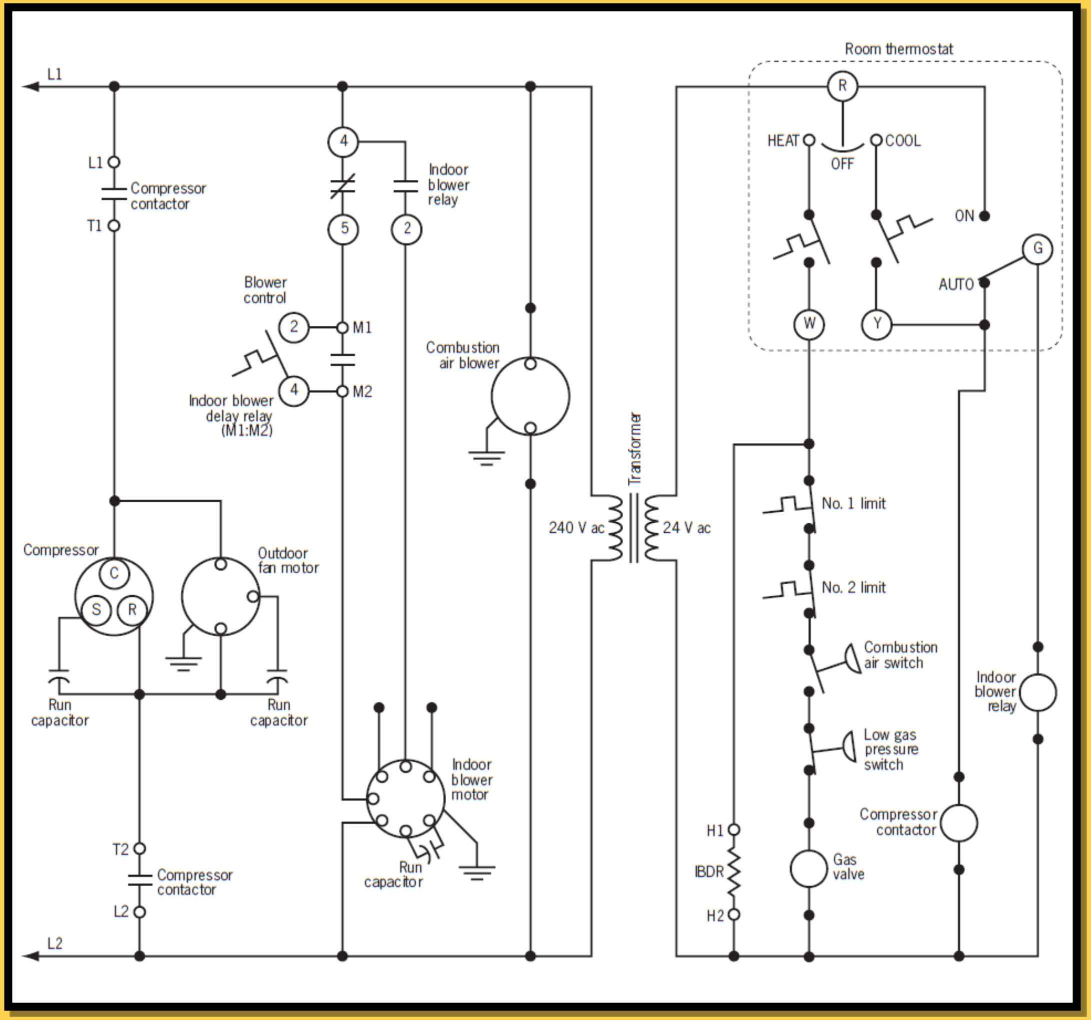
Pictorial Diagram

- Component Diagram.
- Shows the physical layout of the components.



Ladder Schematic

- Shows specific paths.
- Best for trouble-shooting.
- Shows how electricity get through switches and to loads.



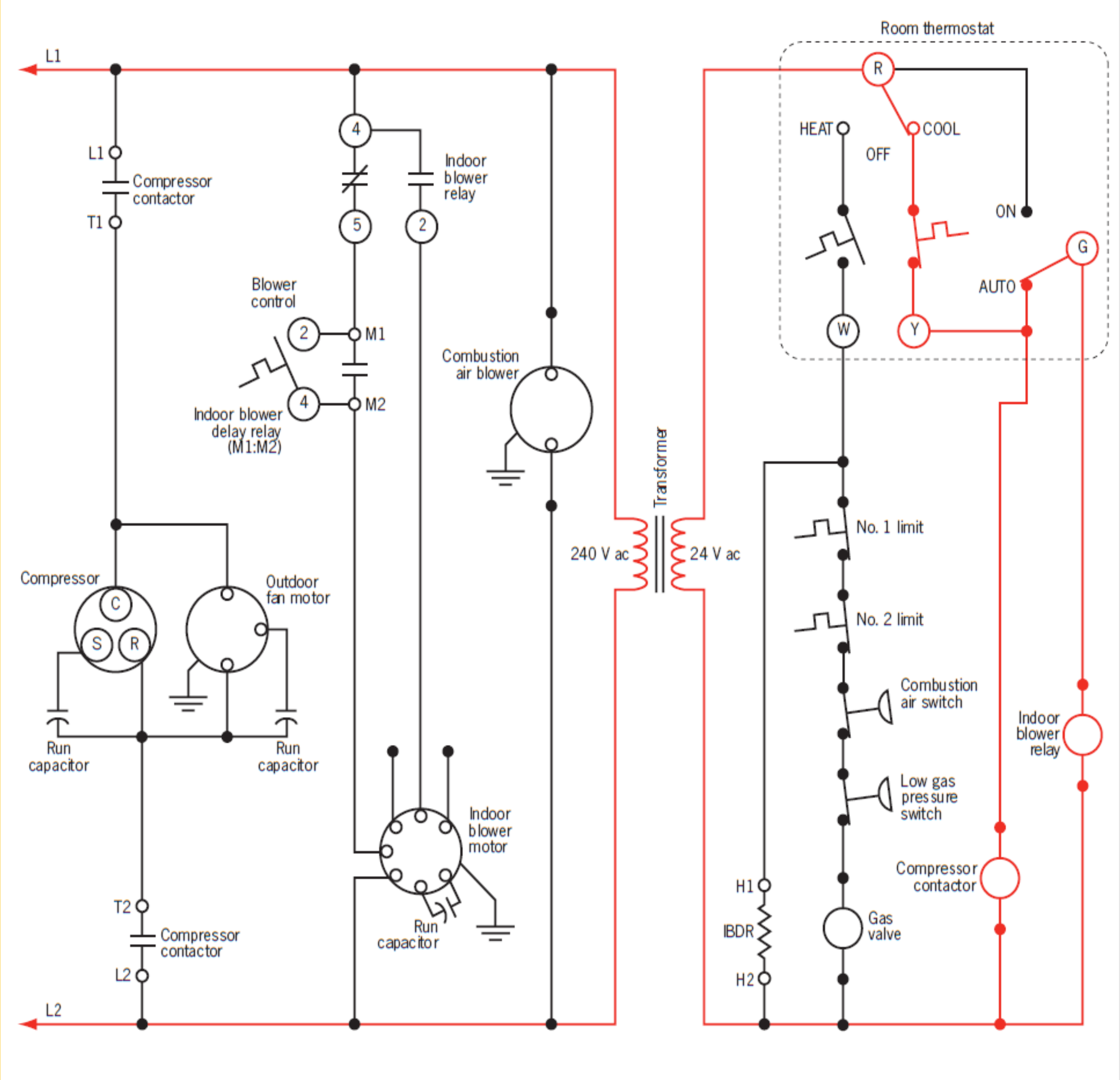
Lines

- Heavy Solid:
  - Factory-installed line voltage.
- Lighter solid:
  - Factory-installed control voltage.
- Heavy dashed:
  - Field-installed line voltage.
- Light dashed:
  - Field-installed control voltage.

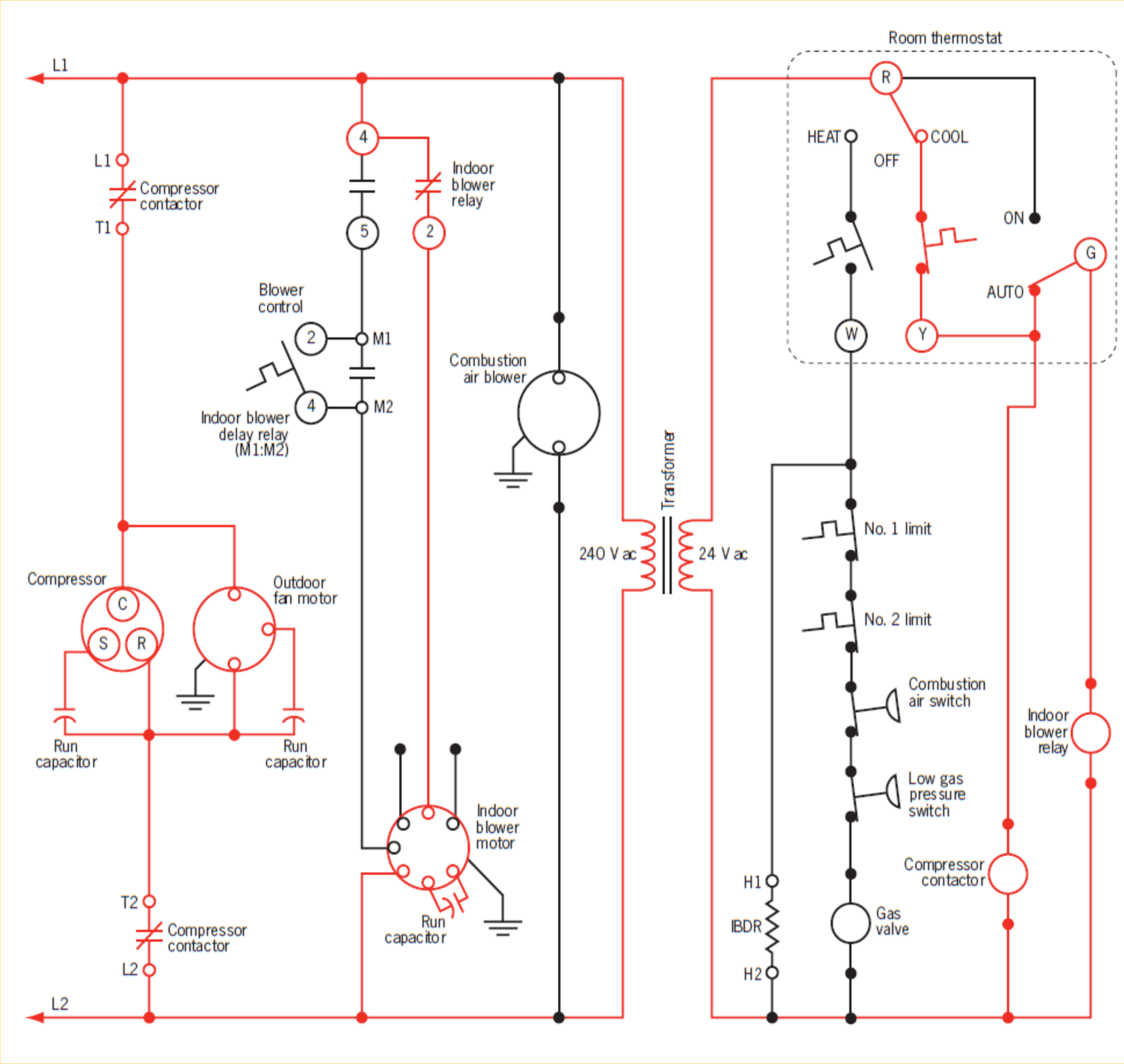
Reading the Sequence of Operation

- Specific circuits will be illustrated on the following pages:
  - Observe the circuits highlighted in red.

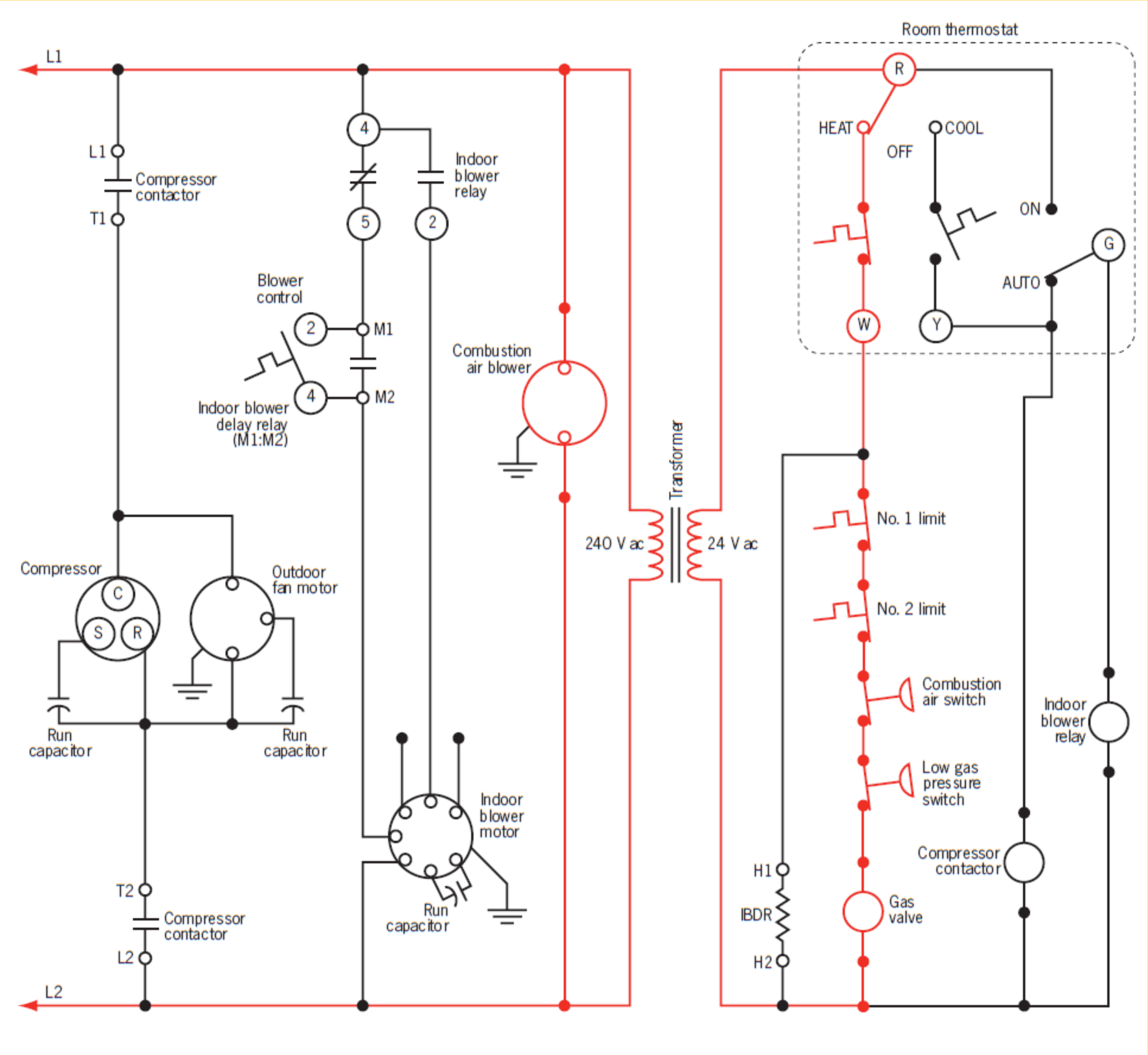
Call for Cooling



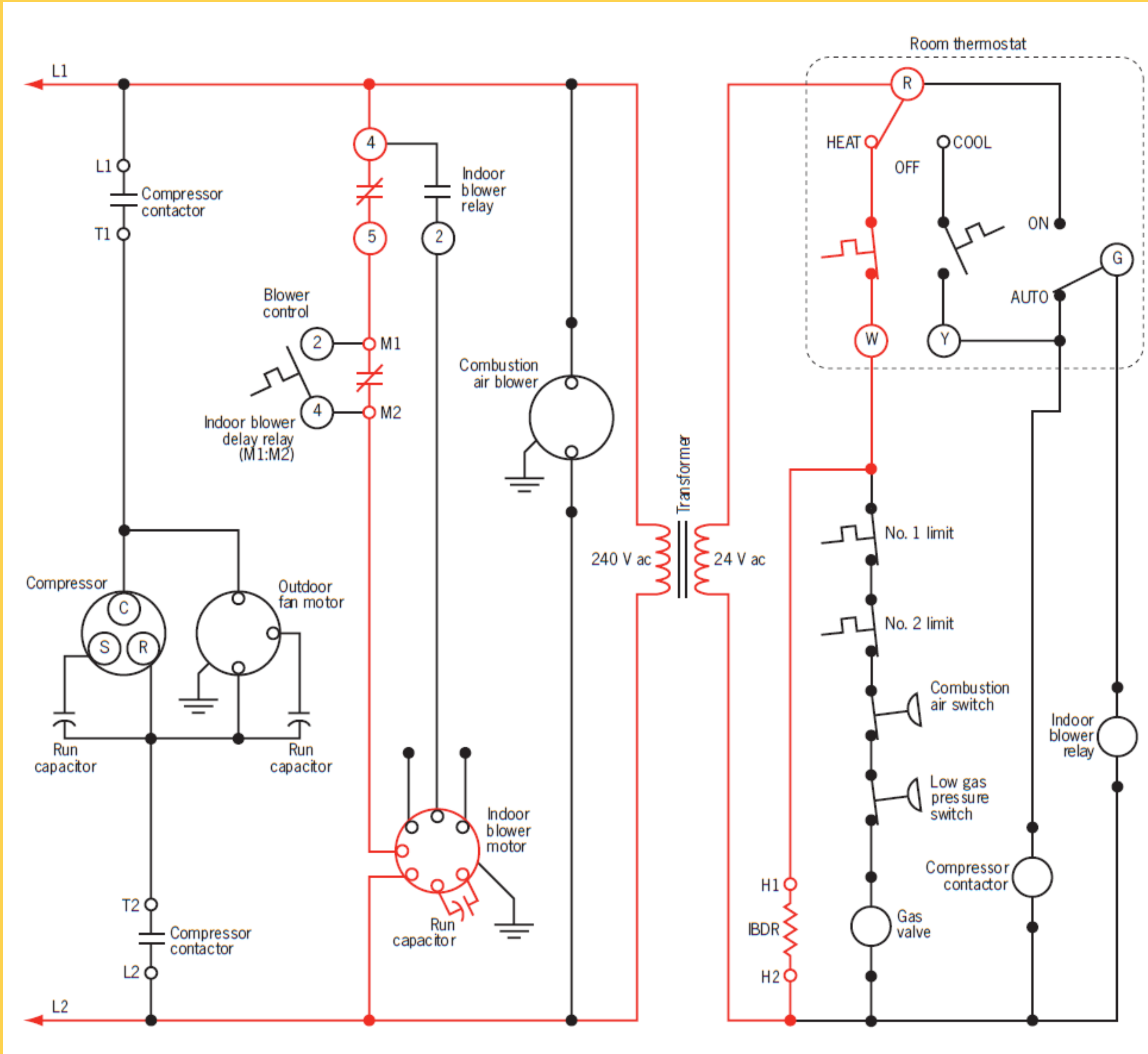
Cooling Cycle



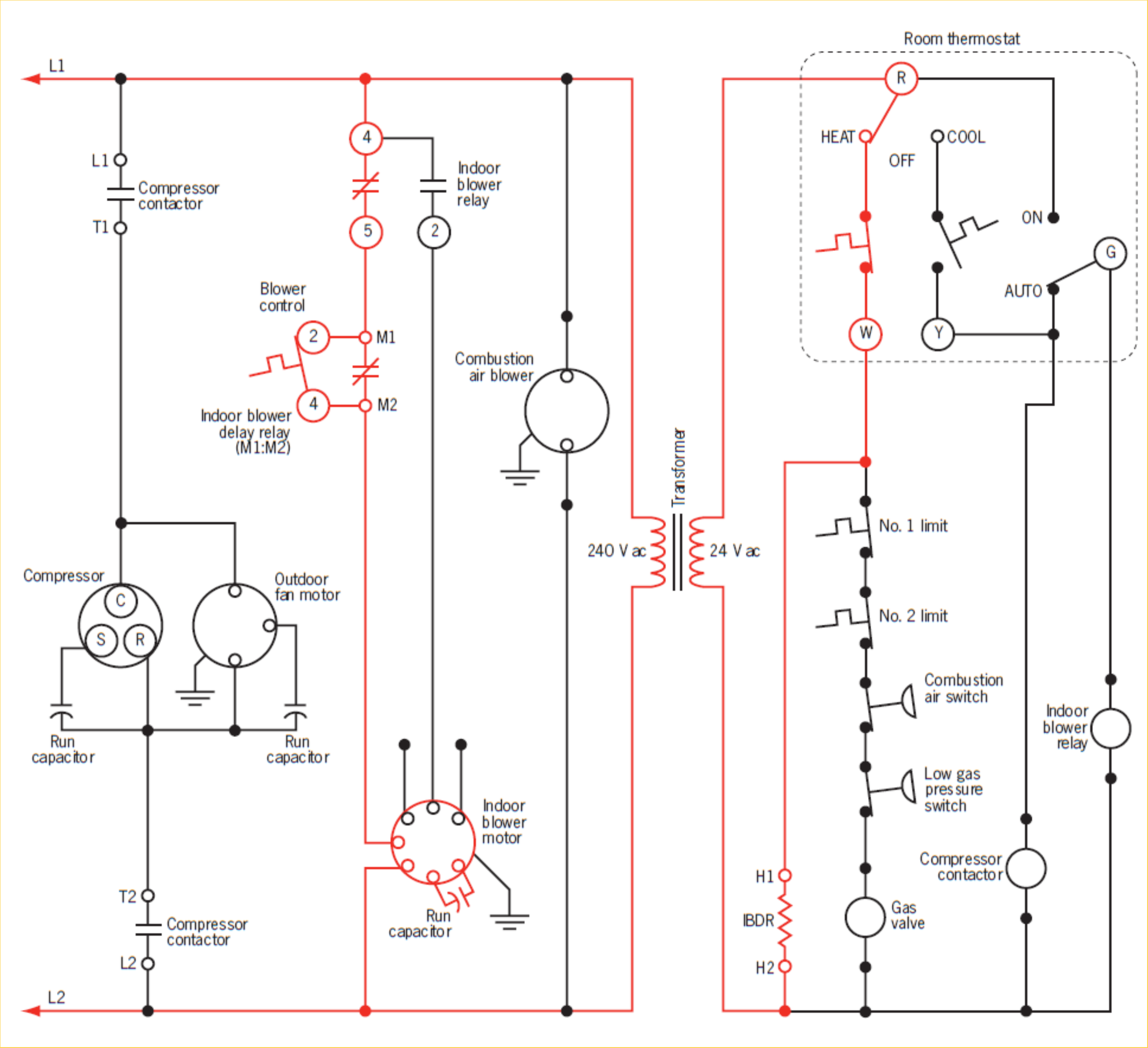
Heating Cycle



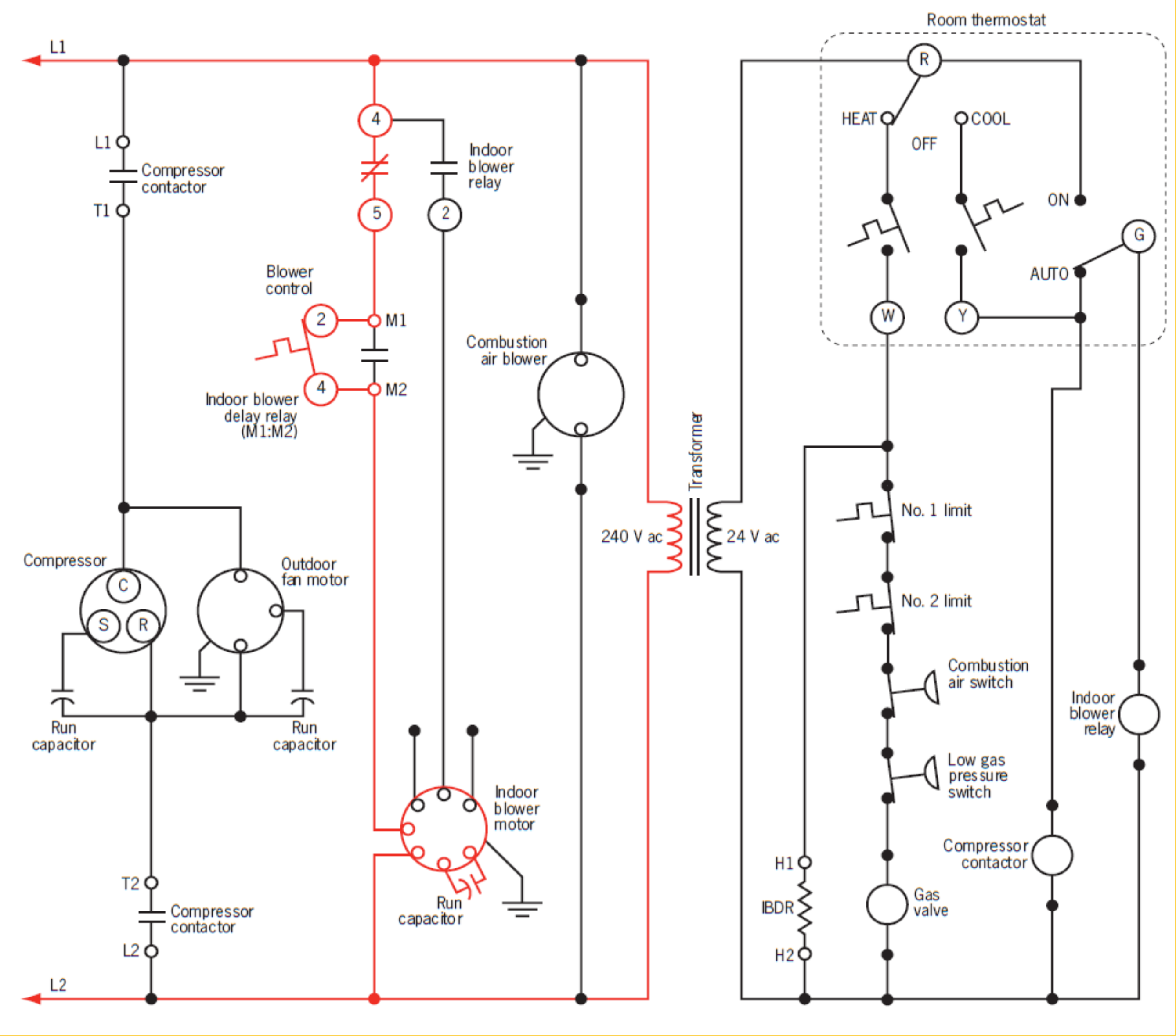
Heating cycle



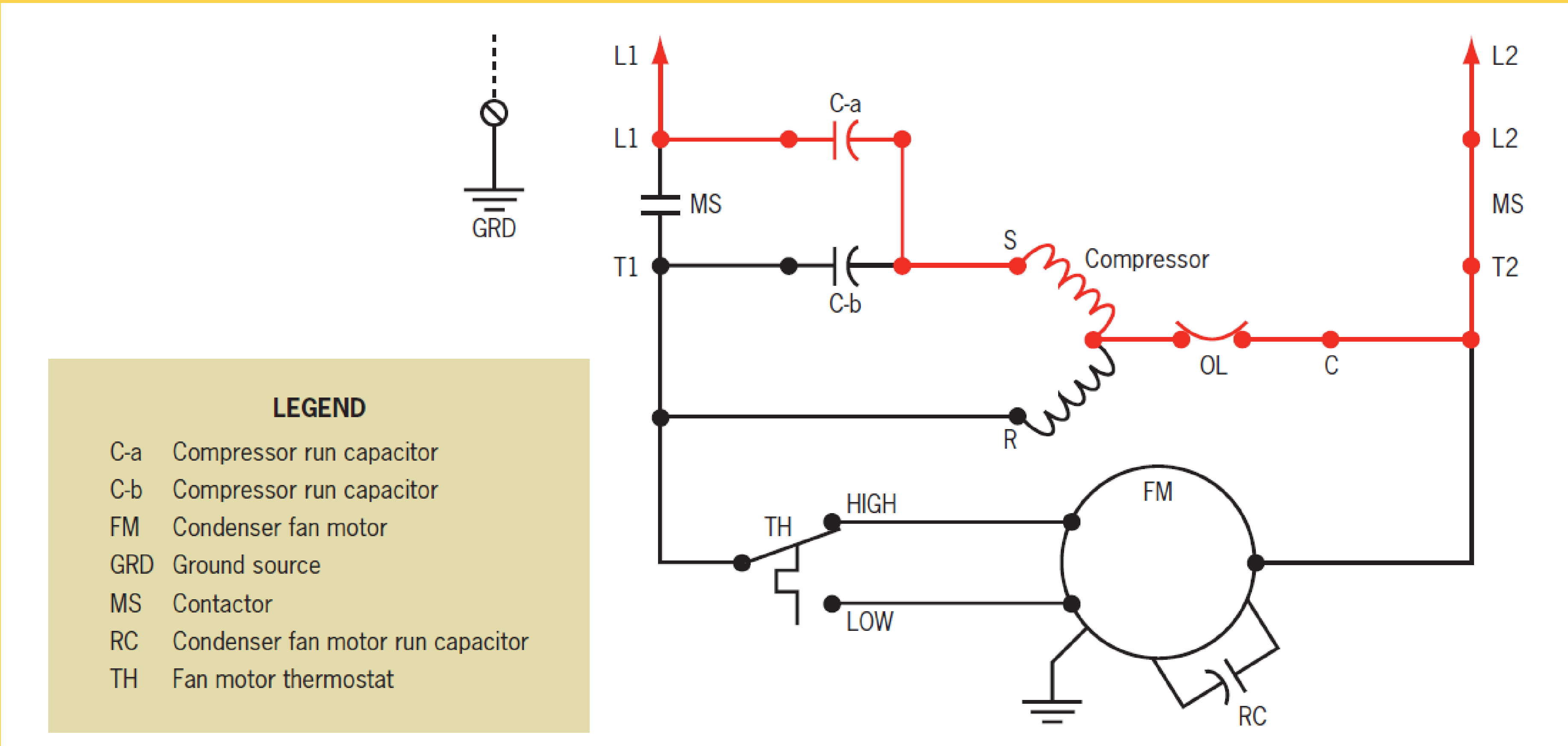
Heating cycle – IBDR circuit



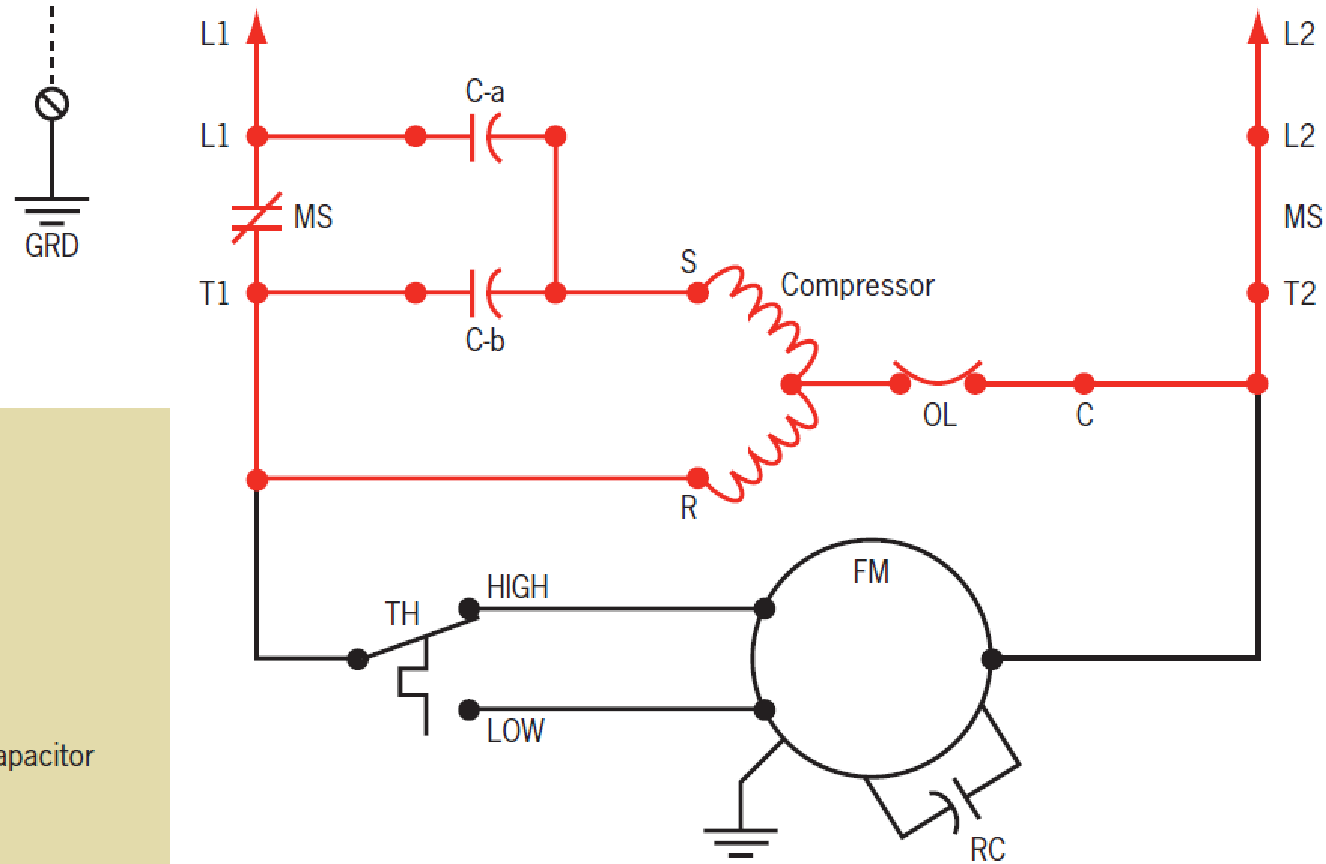
Temperature "OFF" Function



Trickle Heat Circuit



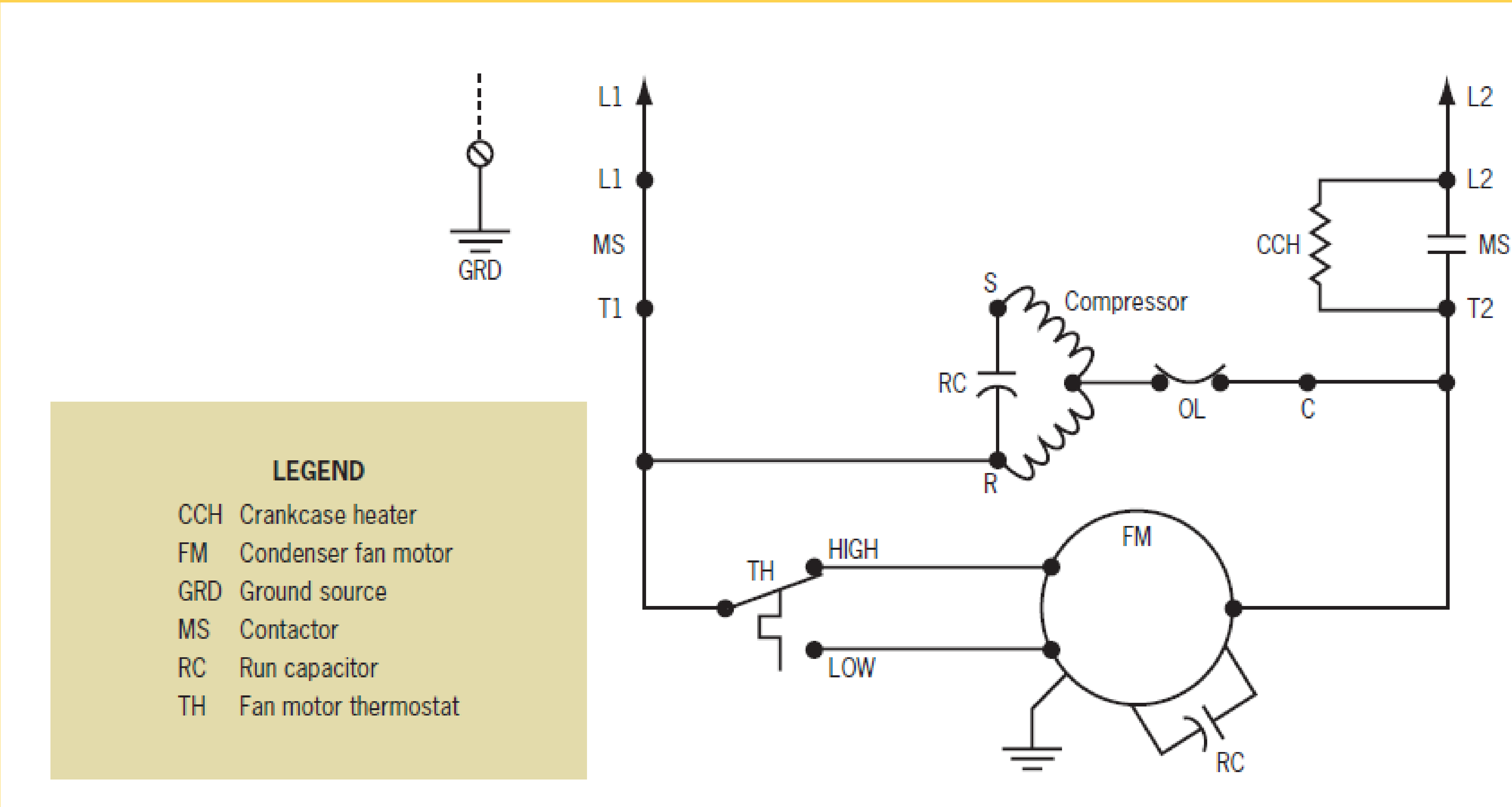
Dual Run Capacitors



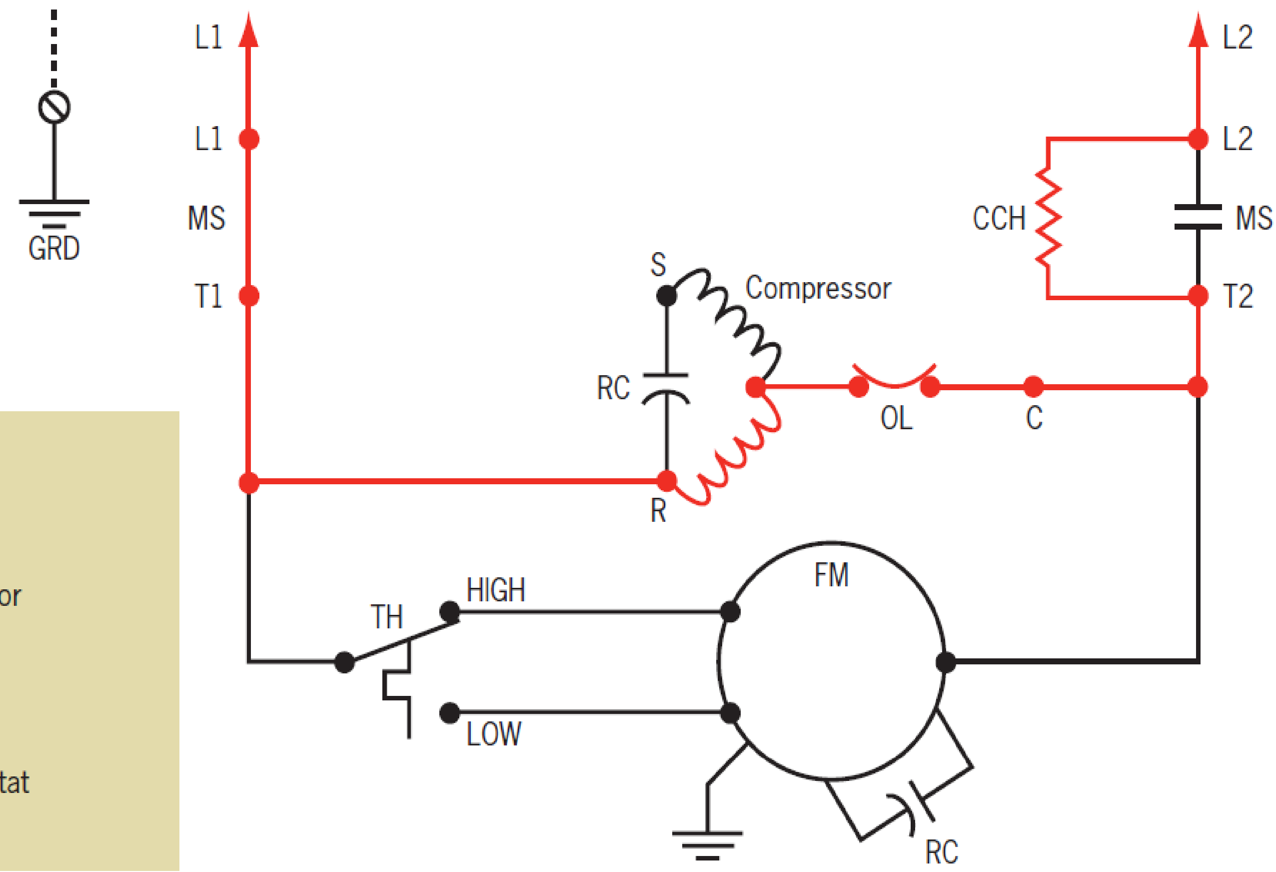
LEGEND

C-a	Compressor run capacitor
C-b	Compressor run capacitor
FM	Condenser fan motor
GRD	Ground source
MS	Contactor
RC	Condenser fan motor run capacitor
TH	Fan motor thermostat

Crankcase Heater Circuit



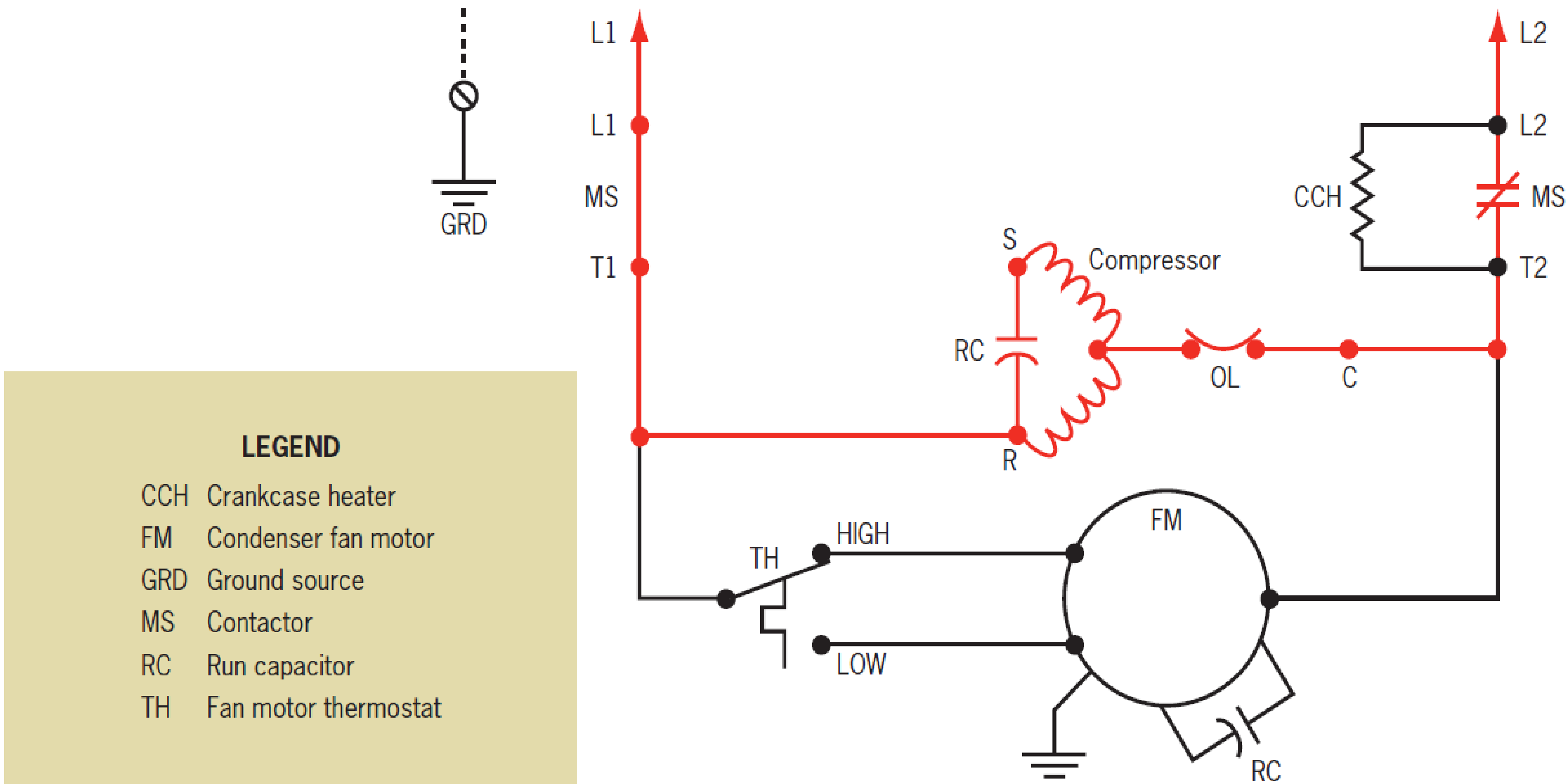
Energized Crankcase Heat



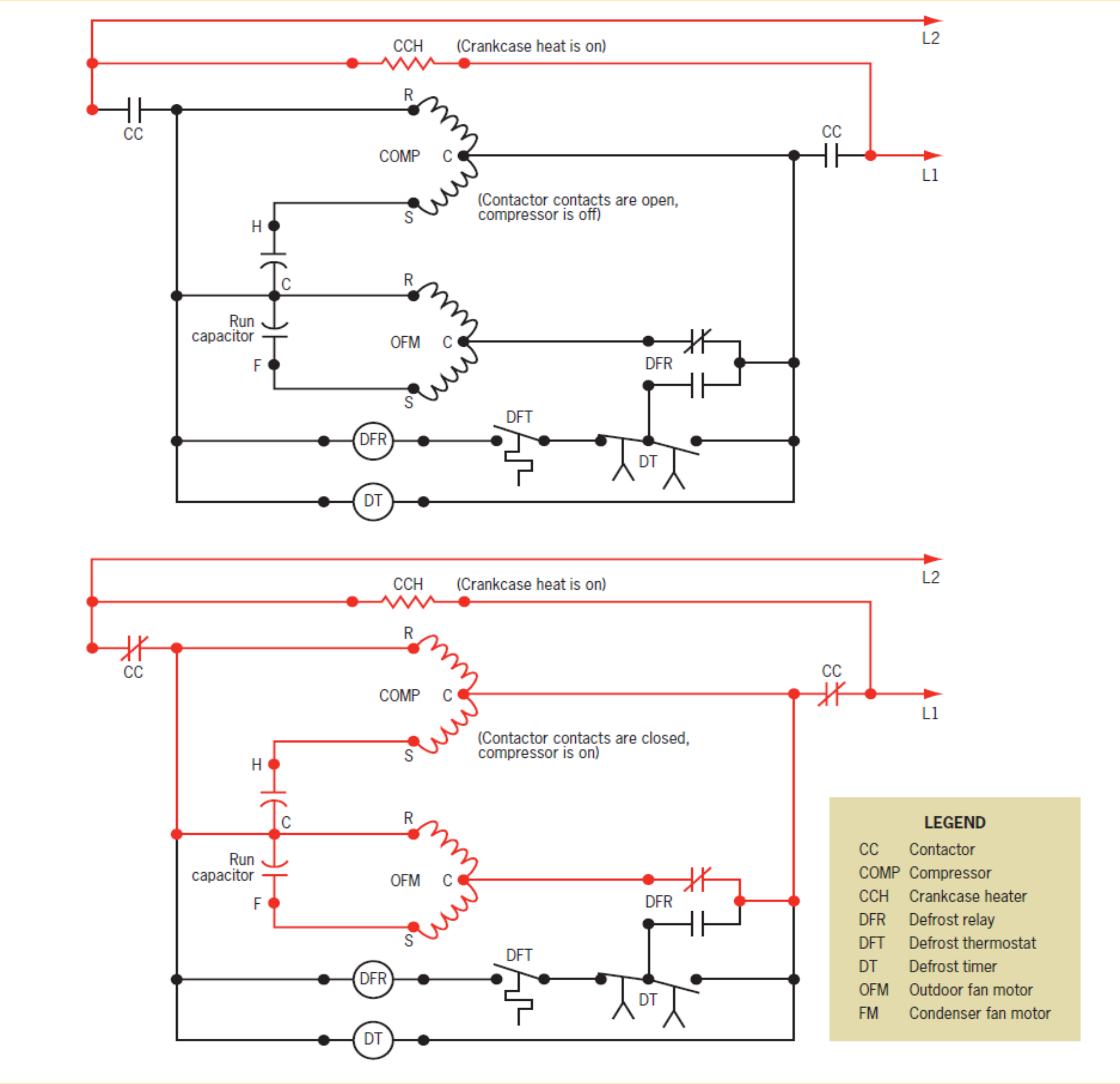
LEGEND

CCH Crankcase heater
FM Condenser fan motor
GRD Ground source
MS Contactor
RC Run capacitor
TH Fan motor thermostat

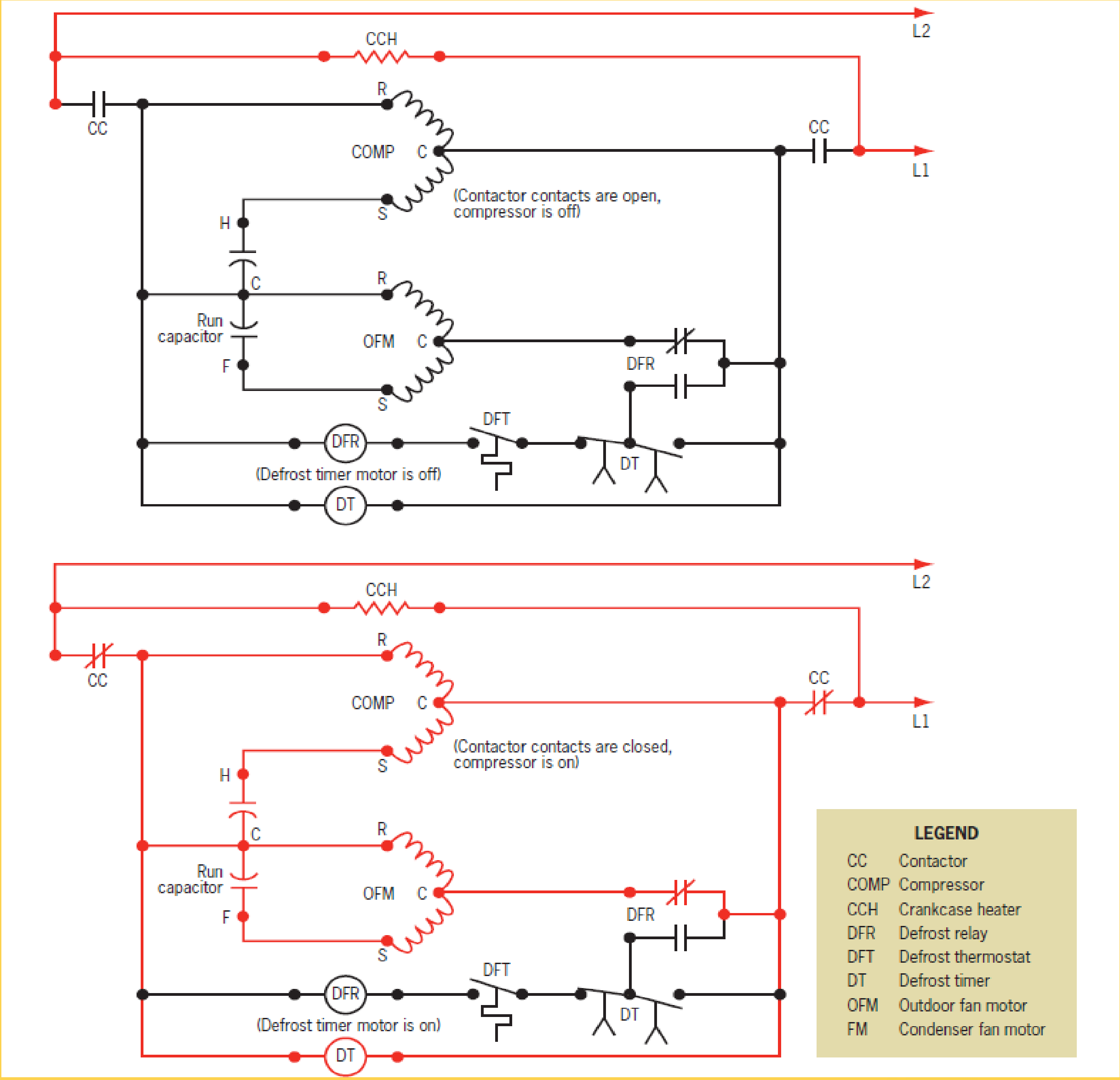
De-energized Crankcase Heater



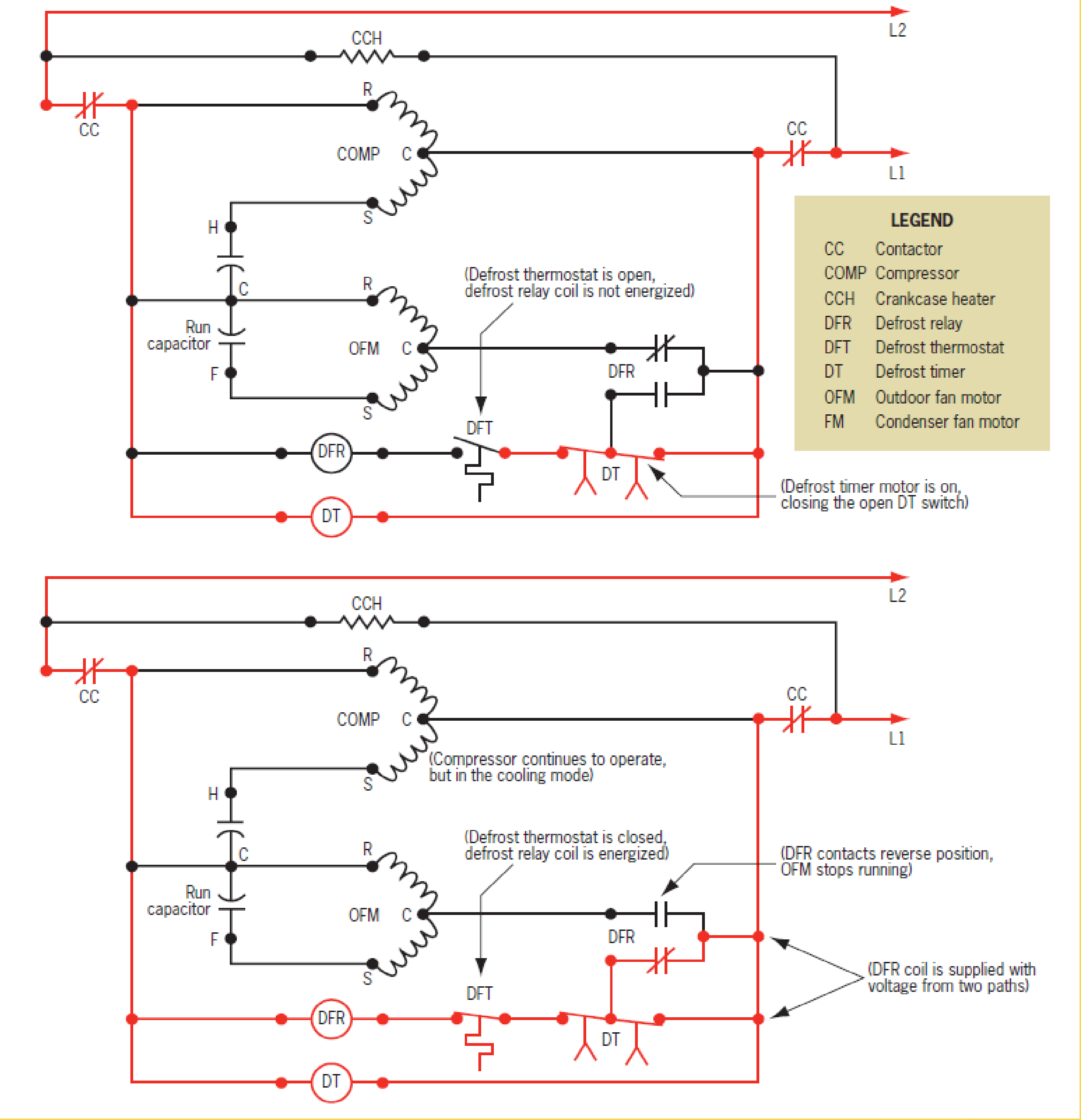
Continuous Crankcase Heat



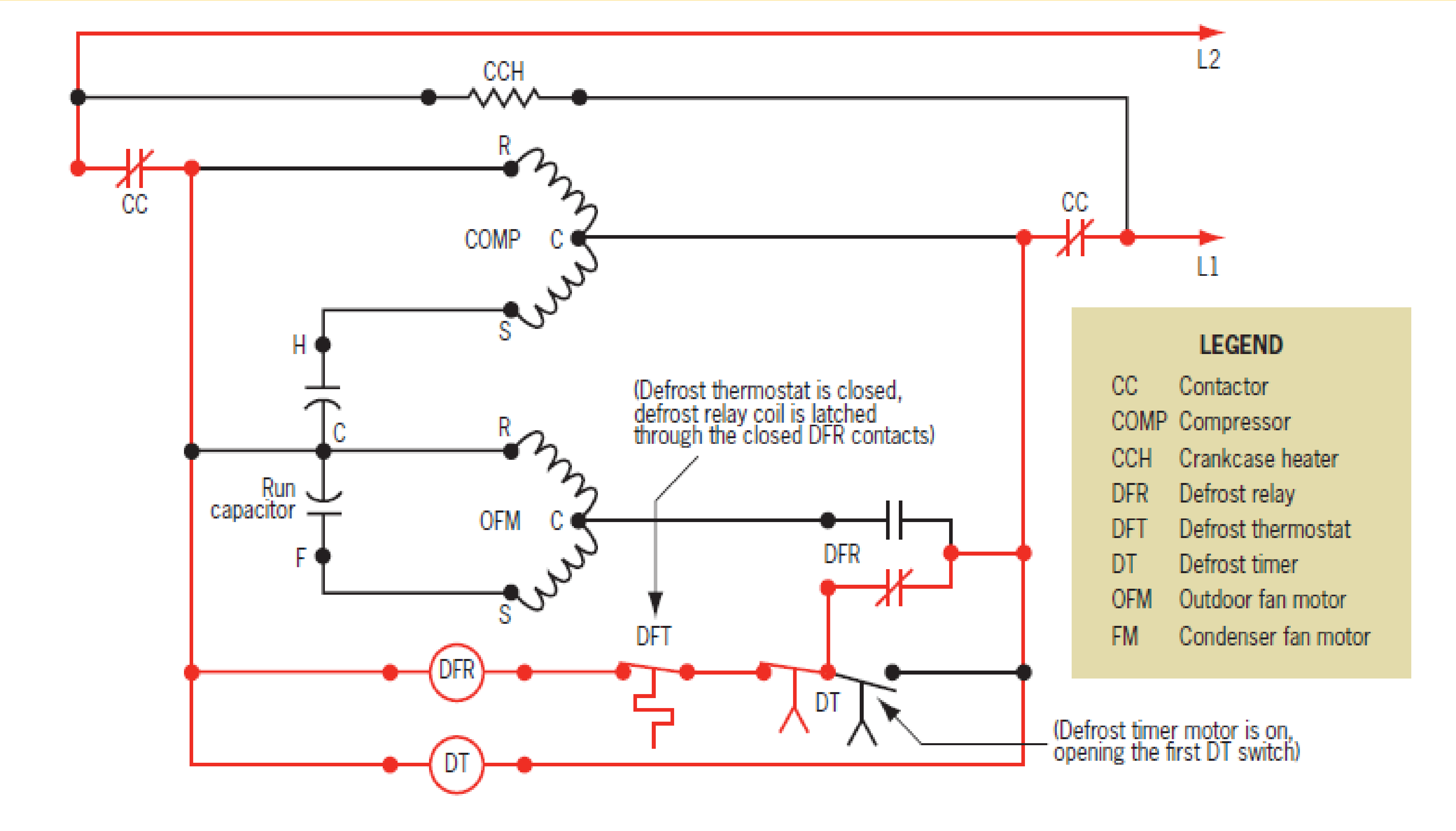
Defrost Timer Motor Circuit



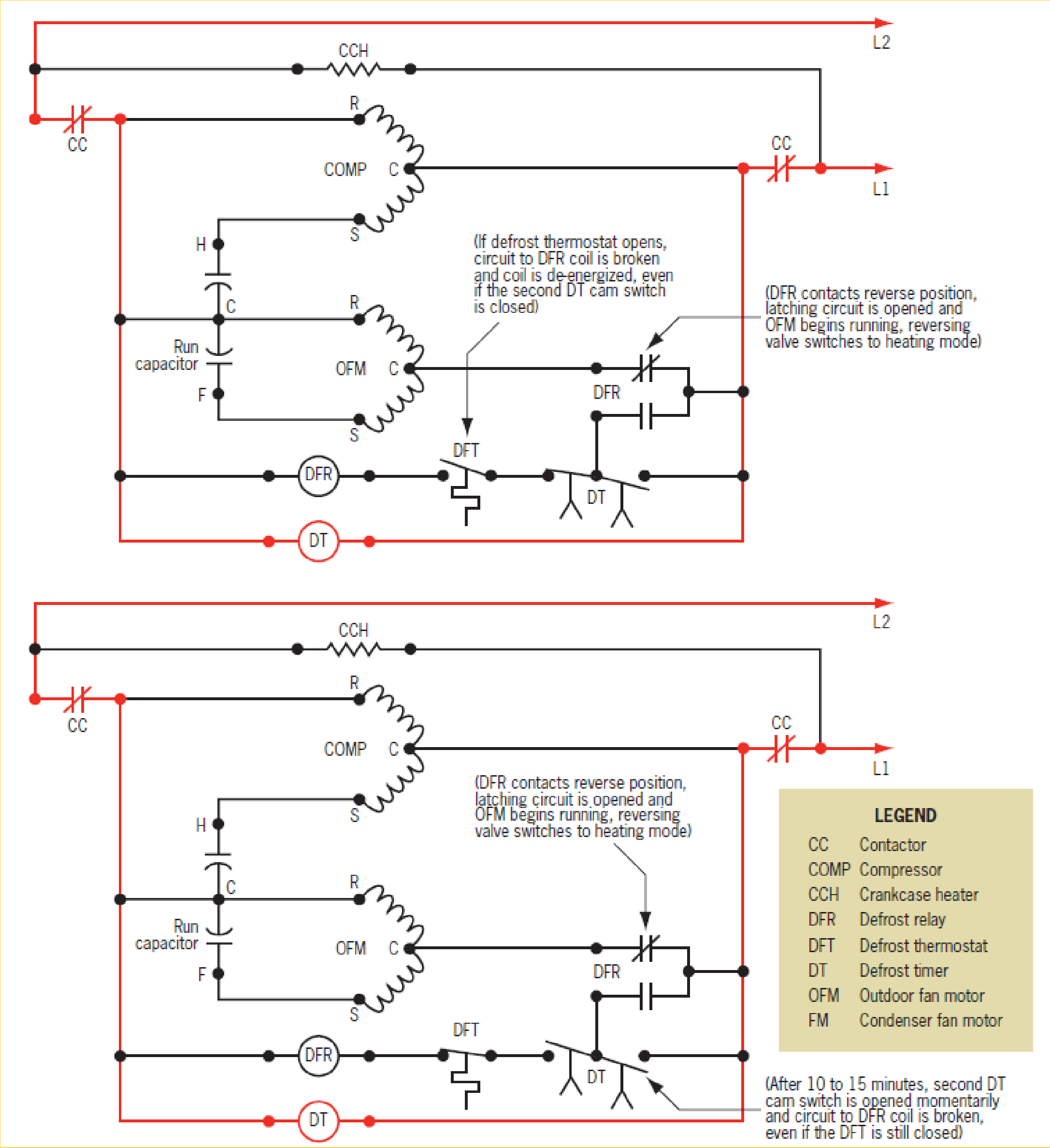
Defrost Initiation



Defrost Latching Circuit

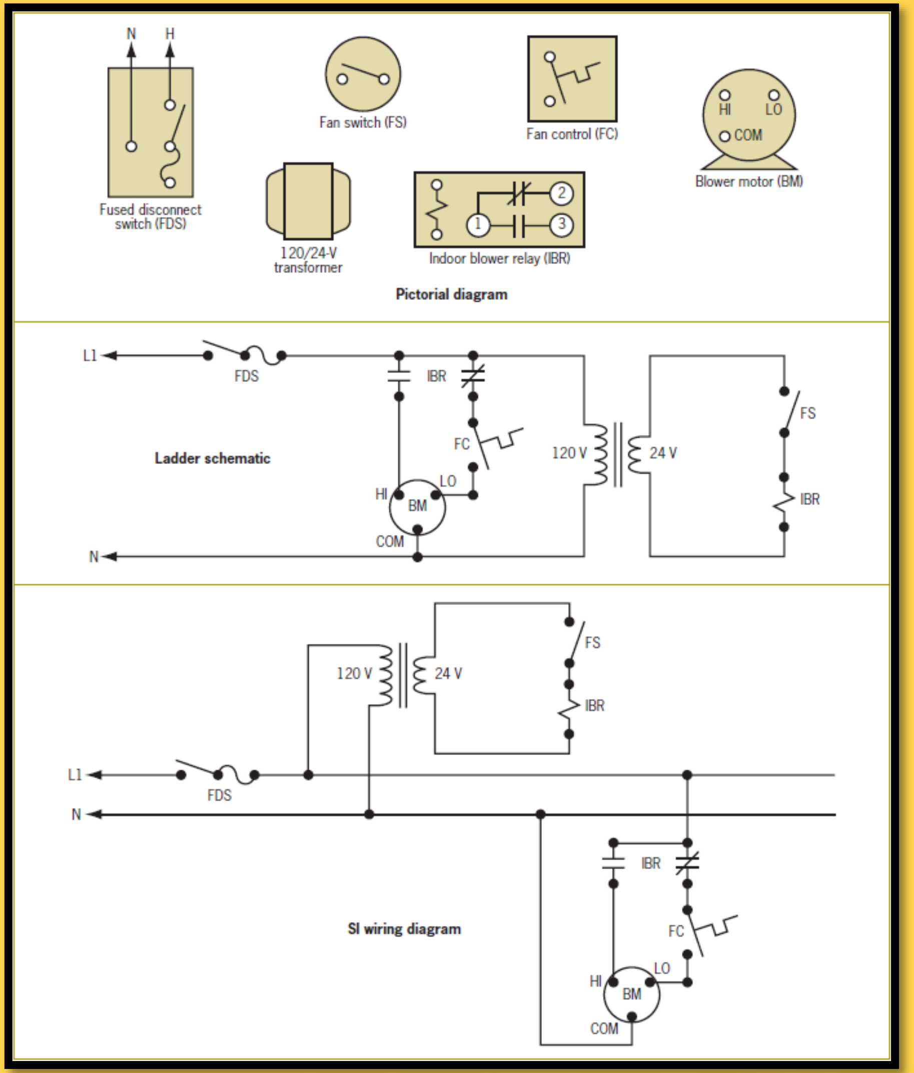


Defrost Termination



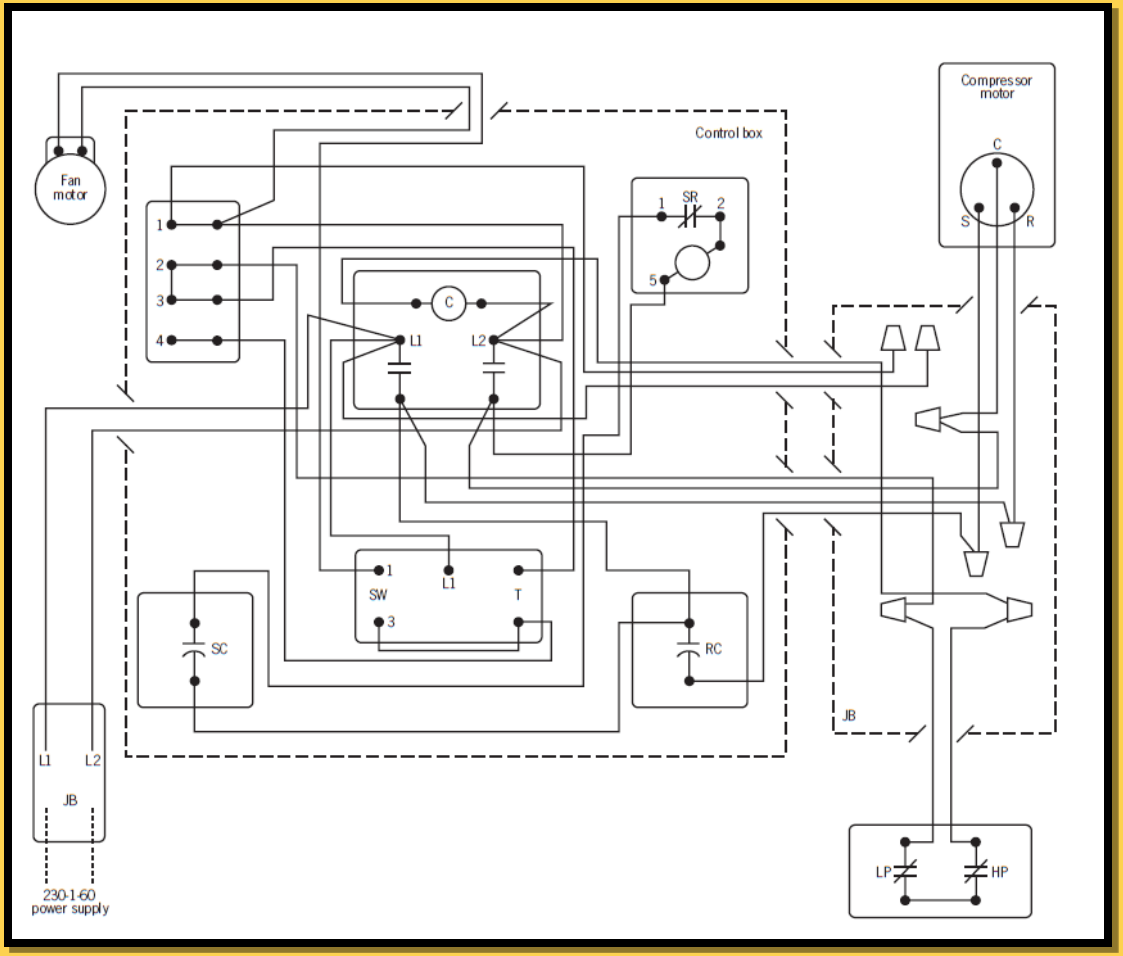
International Wiring Diagrams

- Système of International d'Unités (SI).
- Power source is drawn through the middle of the wiring diagram.
- Low-voltage control circuit is shown above the power source.
- Line-voltage circuitry is shown below the power source.

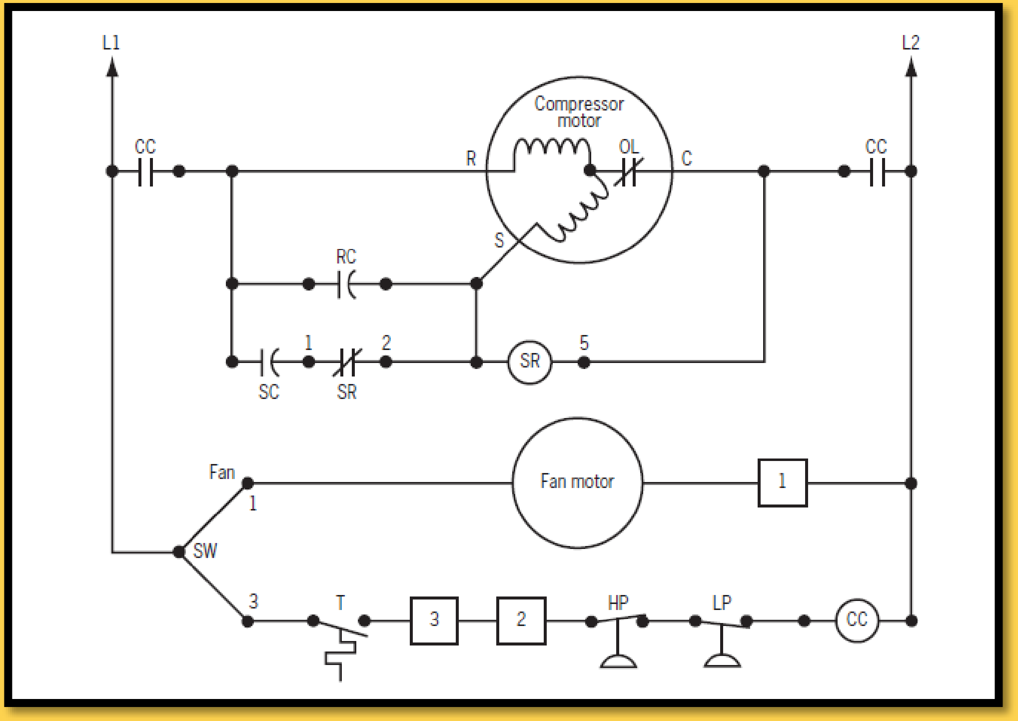


Point-to-point Diagrams

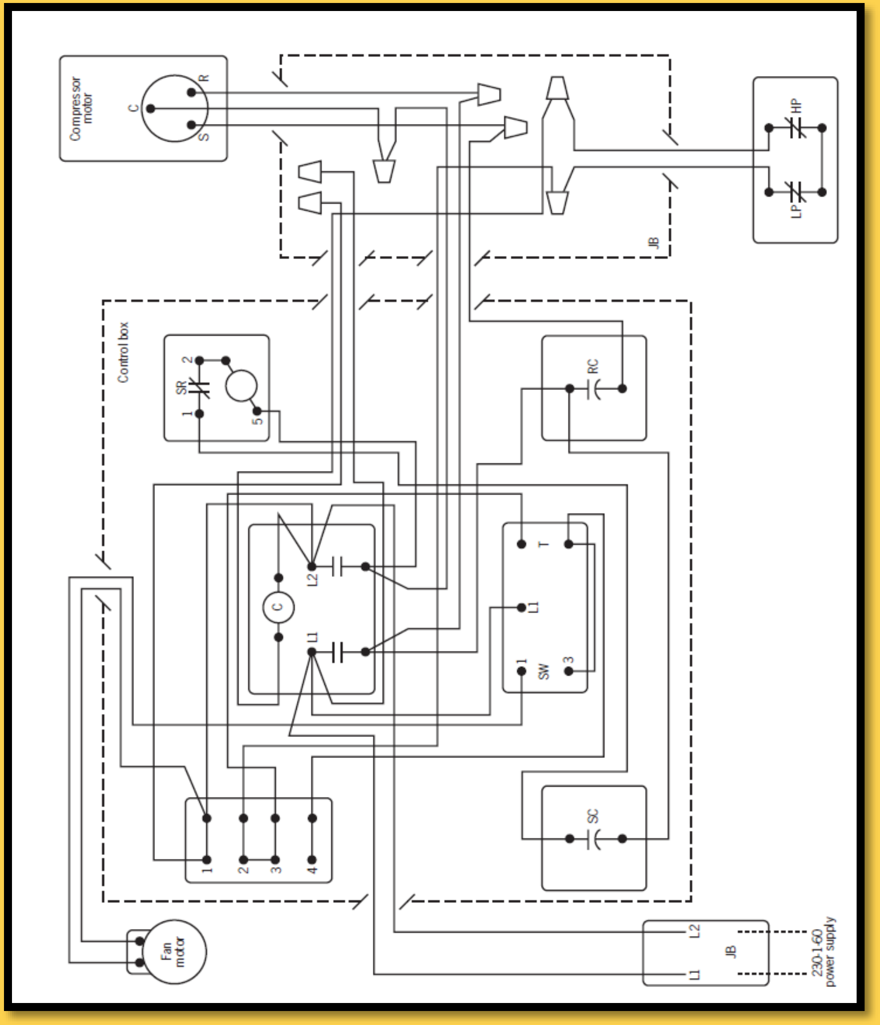
- Point-to-point diagrams show the connection from component to component but not necessarily what takes place at those components.



Ladder vs. Point-to-point Diagrams



Ladder Schematic Diagram



Point-to-point Diagram

Lesson Summary

- A wiring diagram is a road map of an electric circuit.
- 75% of all service calls involve electrical troubleshooting.
- The most common types of wiring diagrams are the pictorial diagram and the ladder schematic.
- The pictorial diagram shows the general location of electrical components in the control cabinet.
- The ladder schematic shows the sequence of operation for the system.
- The use of SI diagrams has gained in popularity among many manufacturers of HVACR equipment.
- Regardless of the type of wiring diagram used, the rules for reading a schematic remain unchanged.
- Practice is important to success as a service technician.

Troubleshooting Electric Circuits

Chapter 7

Lesson Objectives

- Understand safety procedures and precautions.
- Recognize meter types and application.
- Measure voltage, amperage and resistance.
- Understand electrical component function and troubleshooting.

Introduction

- Electricity operates HVACR components.
- Electricity cannot be taken for granted:
  - Its benefits come with risks for technicians.

Safety

- Current flow causes a shock:
- A higher voltage allows a greater current to flow through the resistance of the body:
  - Low voltages can be deadly under the right conditions.
  - Exposure to about 1 mA (0.001 A) causes the sensation of shock.
  - Exposure to approximately 10 to 20 mA (0.01 to 0.02 A) causes shock severe enough to paralyze muscles, preventing a person from releasing the object conducting current.
  - Exposure to as little as 100 to 200 mA (0.1 to 0.2 A) can be fatal if it lasts for one second or more.

Safety

- Most low-voltage electrocutions are the result of the failure to lock out, disconnect or isolate power.
- Use insulated gloves and tools.
- Use GFCIs.
- Electricity is a form of energy.
- HVACR professionals have a responsibility to exercise great care.

Tools and Instruments

- Proper tools are a must.
- Instruments must be well-maintained and correctly calibrated.
- The majority of the electrical measurements that you will take as a technician are readings of alternating current (ac).
- Motors, electric heaters, magnetic coils, transformers and most other electrical loads in HVACR equipment operate on alternating current.
- In some control circuits, direct current (dc) is utilized, so you must be prepared to work with dc circuits as well.

Electrical Meters

- Volts.
- Current.
- Resistance.
- Analog vs. digital.

Digital Multimeter

Meter Category

- CAT I
  - Protected electronic circuits not directly connected to line power.
- CAT II
  - Plug-type loads and receptacle level loads.
- CAT III
  - Distribution-level loads – HVAC work.
- CAT IV
  - Power lines at the utility connection, as well as any overhead or underground outside cable runs.

Meters

- Check CAT and voltage ratings.
- Approved testing agency UL and CSA.
- Check for proper fuses.
- Check test leads for proper CAT ratings:
  - Shrouded test leads;
  - Finger guards; and
  - Visually inspect insulation.

Visual Inspection

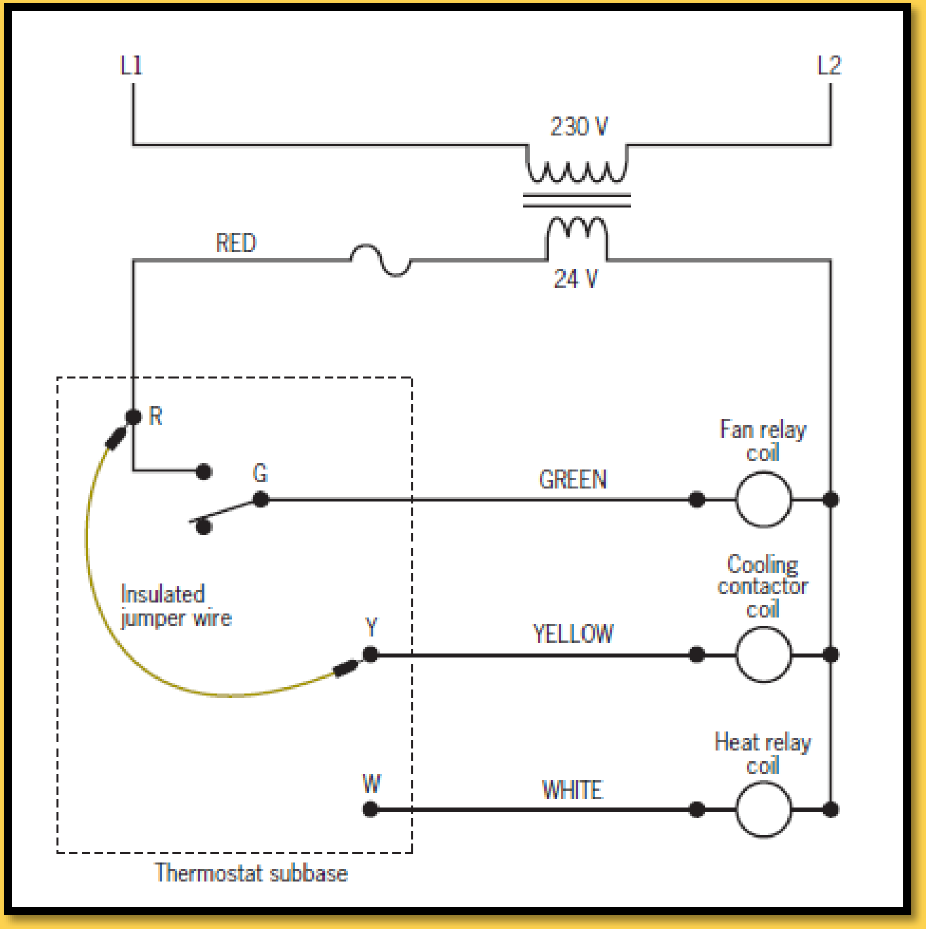
- Start troubleshooting with a visual inspection:
  - Is the thermostat set to operate?
  - Is part of the system running?
    - Compare to sequence of operation from wiring diagram.
    - Turn fan to “ON.”
  - Look for loose connections.
  - Look for overheated terminals or contacts.
  - Look for damaged wires.

Fuses

- Proper type:
  – Current;
  – Voltage; and
  – Delay.
- Testing:
  – Visual;
  – Voltage; and
  – Resistance.
- Before replacing a bad fuse determine what caused the fuse to blow.

Thermostat

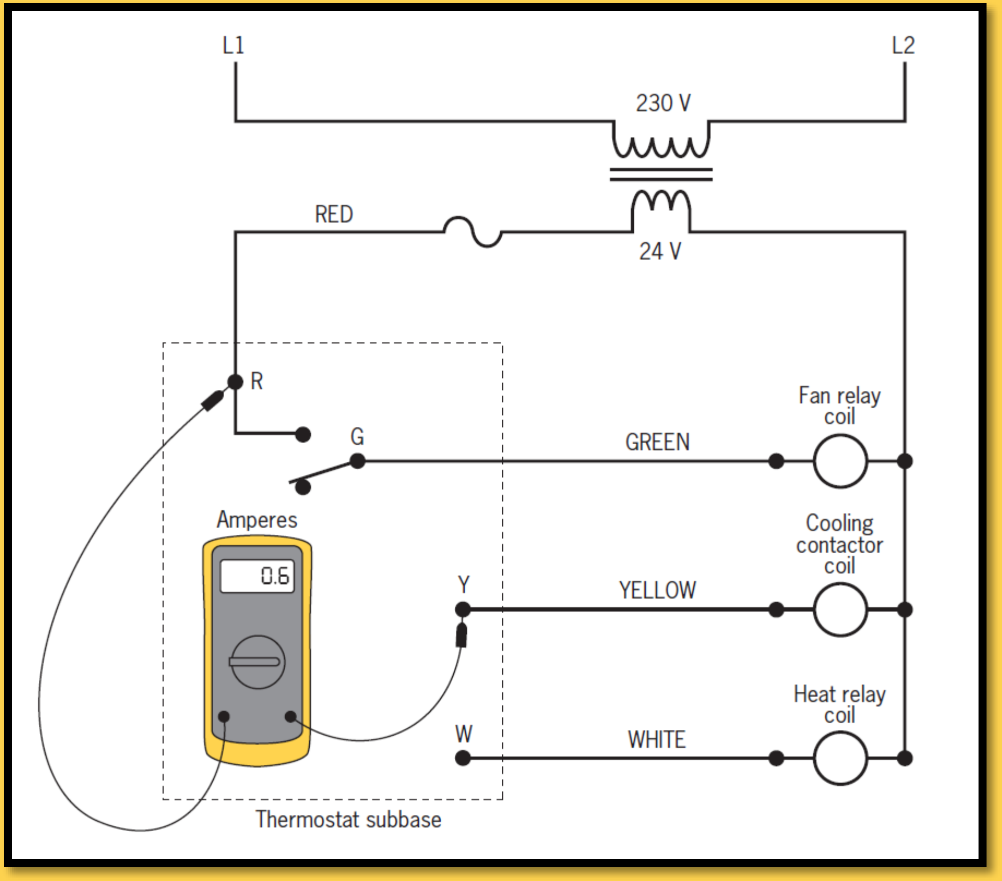
- Terminal identification:
  - R – power.
  - W – heat.
  - Y – cooling.
  - G – fan.
- Testing.



Basic Thermostat

Current Draw Measurement

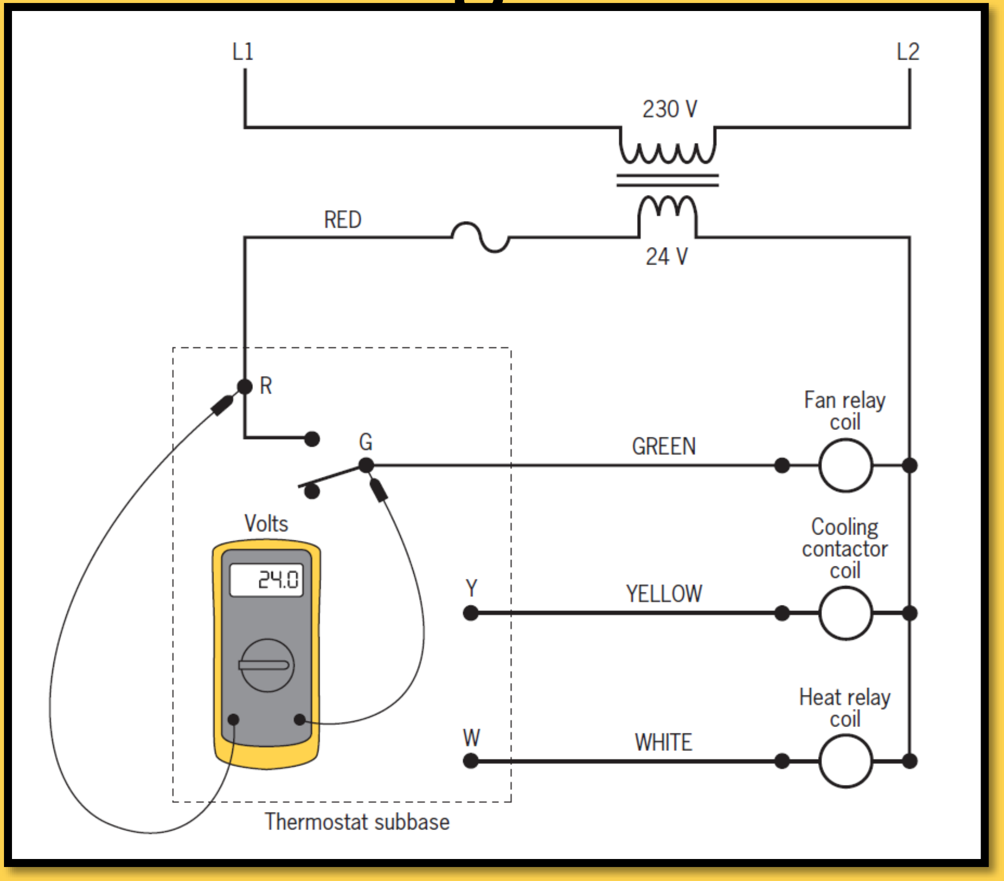
- Use meter instead of insulated jumper.
- Measure current draw of each circuit.
- Amperage higher than 1A is indicative of a problem.



Using a multimeter to read current draw

Fan Circuit Testing

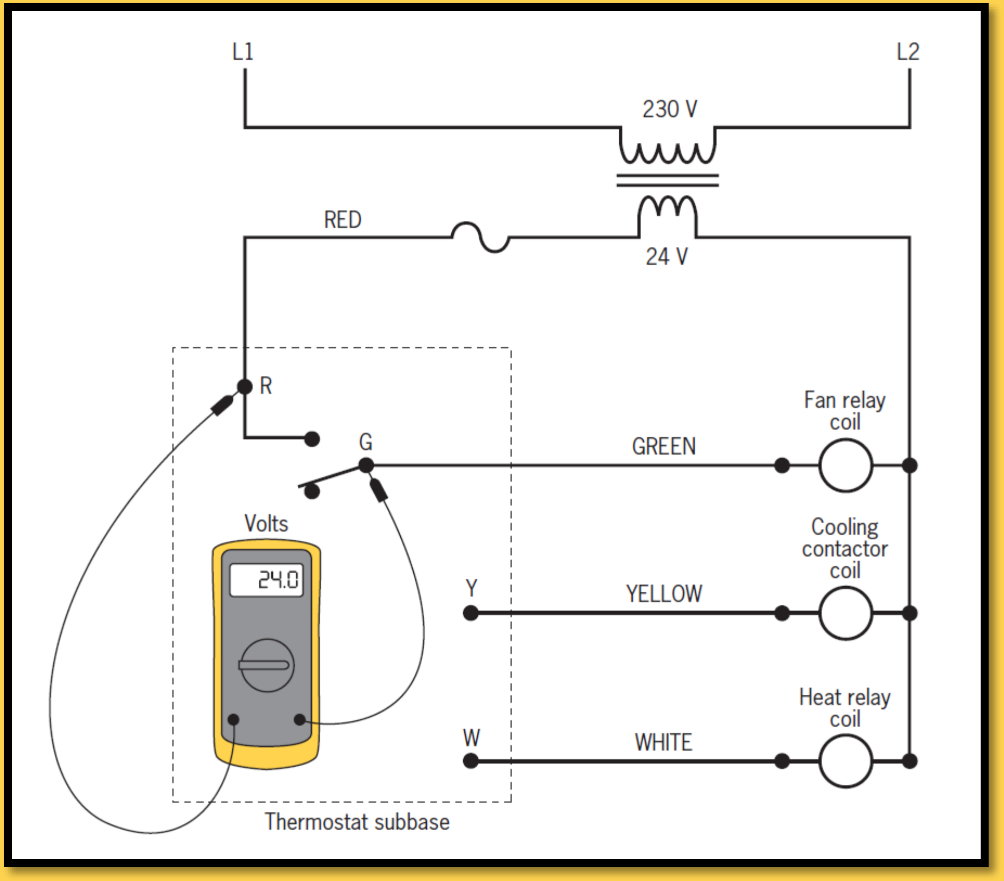
- With the thermostat removed from the subbase, move the fan switch to the “ON” position.
- If the fan fails to start, connect the “R” terminal to the “G” terminal:
  - If the fan starts at this point, the subbase is defective and must be replaced.



Subbase Fan Circuit Voltage Reading

Fan Circuit Testing

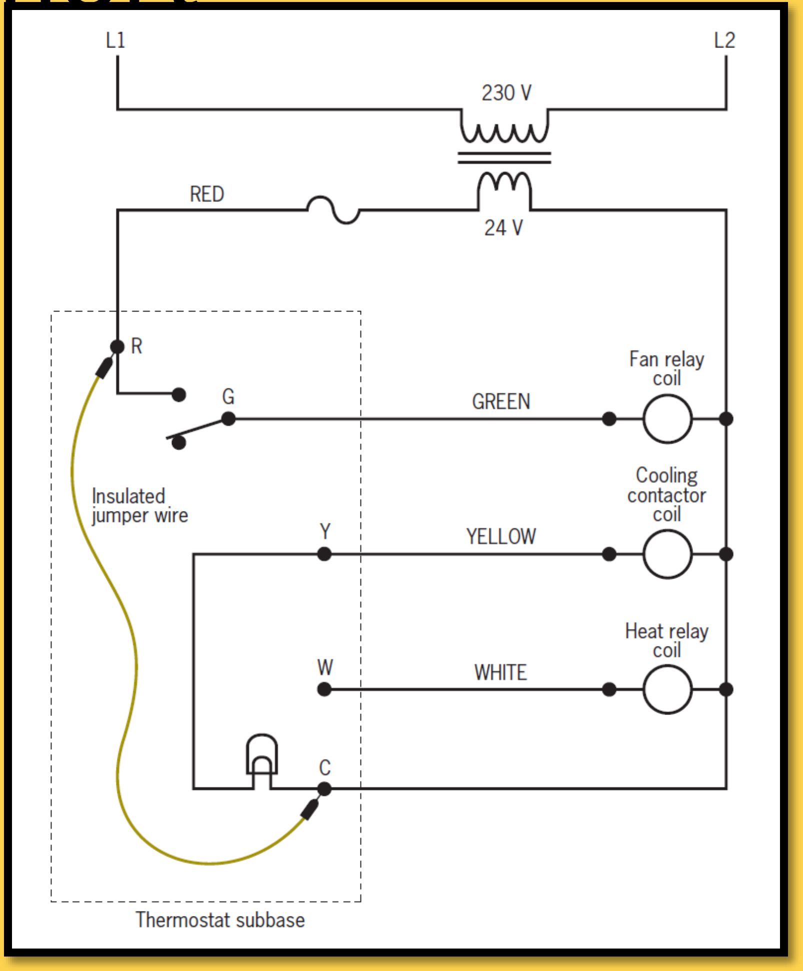
- If the fan fails to start with the jumper connected, there is most likely a problem with the system transformer, the fan relay coil or the circuit wiring.
- The fan should turn off when the fan switch is moved to the "AUTO" position. You should be able to measure 24 V between the "R" terminal and the "G" terminal on the subbase.



Subbase Fan Circuit Voltage Reading

Direct Short

- Use caution when using a jumper wire.
- Connecting "R" to "C" is a direct short:
  - May blow the fuse or damage the transformer.



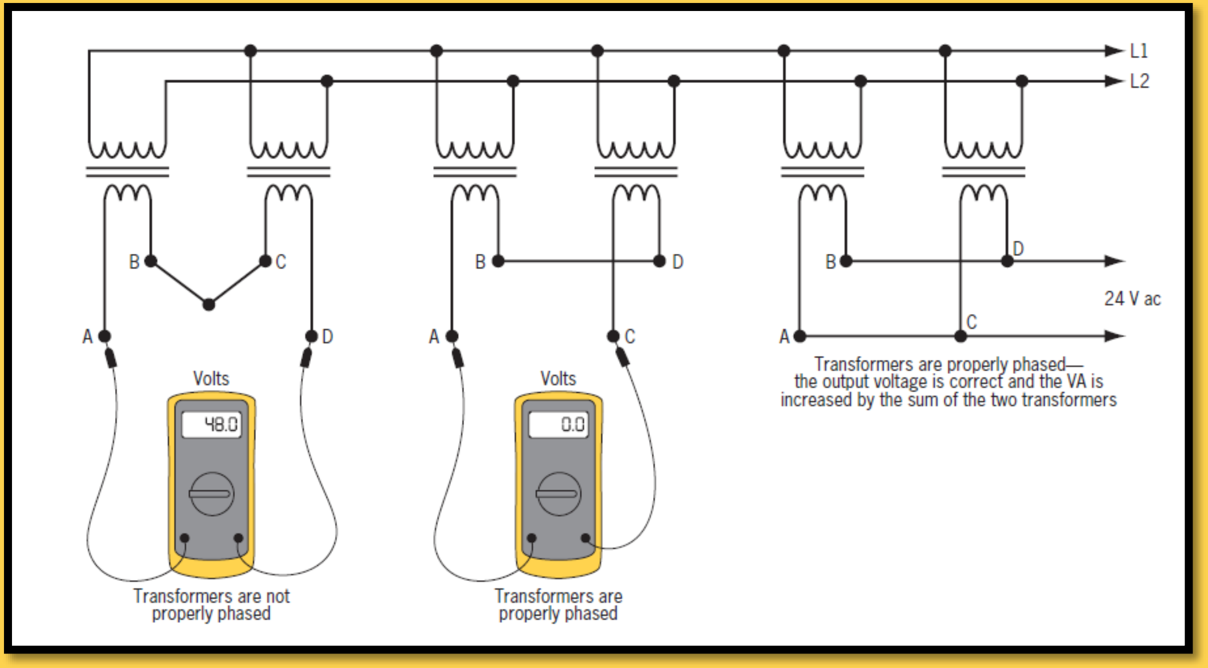
Direct Short Situation

Transformers

- Check connection per the wiring diagram, including taps if a multi-tap transformer.
- Verify line voltage to primary, 24 volts AC should be measurable at the secondary.
- Remove from the circuit and measure resistance of the primary and secondary.

Transformers

- Transformers can be connected in parallel to increase the VA rating.
- Check for proper phasing.



Phasing Transformers

Pressure Controls

- May be used as safeties or operating controls.
- Can be electrically tested as any other switch:
  - Zero volts is measurable across closed contacts.
- Switch must open and close at the correct time and/or pressure.
- With a voltmeter across the contacts and a manifold gauge connected, the open and close points may be verified.

High-pressure-switch Evaluation: Case 1

Case 1: The high-pressure control is installed on the system.

- Set the control to cut out at a pressure approximately 20 psig higher than the normal operating head pressure of the system.
- Turn the system on.
- The contacts should be closed and the system should operate as normal.
- Slowly lower the pressure setting on the control until the system shuts off.

High-pressure-switch Evaluation: Case 1

Case 1: The high-pressure control is installed on the system.

- Compare the pressure at which the system shut down to the pressure setting of the control.
- If these pressures are equal, you may adjust the control setting to the desired cutout pressure. Because the control is in calibration, the cutout pressure should be very close to the control setting.

High-pressure-switch Evaluation: Case 2

Case 2: The high-pressure control is not installed on the system.

- Connect the leads of your ohmmeter across the contacts of the control. The meter should indicate continuity because the contacts are normally closed.
- Connect the transmission line from the pressure control to the high-side port on your gauge manifold.
- Connect the center hose of your gauge manifold to the regulator on a nitrogen bottle.
- Open the valve on the nitrogen bottle and set the regulator to a pressure just higher than the desired cutout pressure of the control.

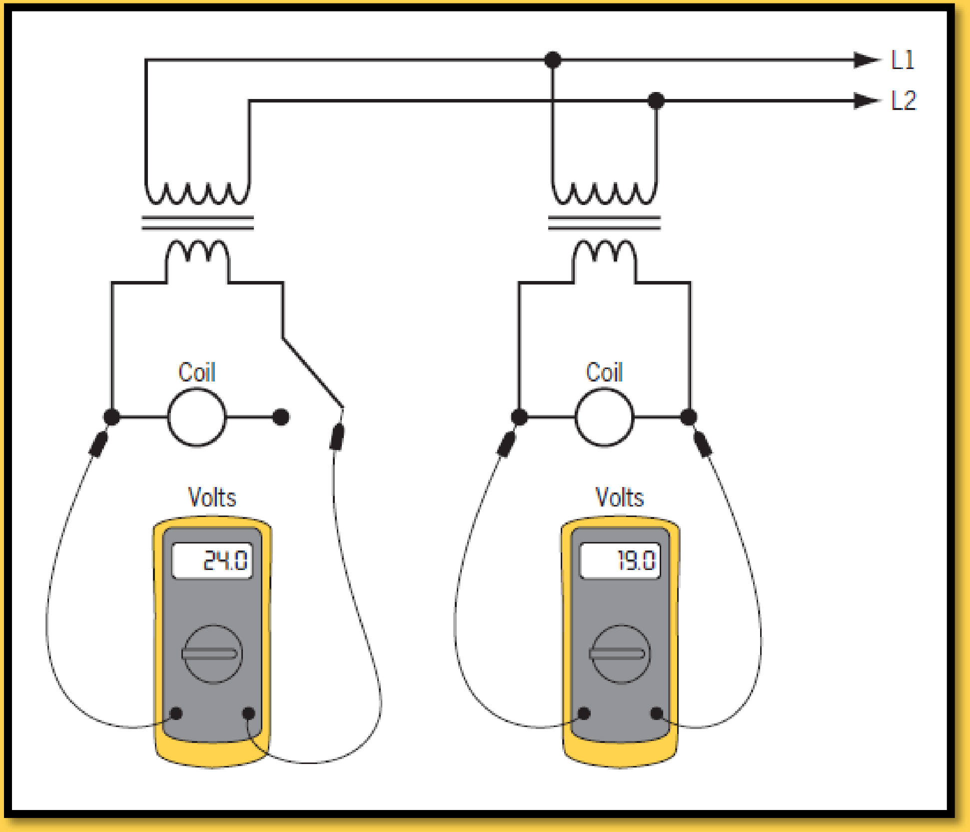
High-pressure-switch Evaluation: Case 2

Case 2: The high-pressure control is not installed on the system.

- Slowly open the high-side valve on the gauge manifold, allowing the nitrogen to enter the high-pressure control.
- When the contacts open, your meter will no longer indicate continuity. An infinity reading will be indicated when the contacts open.
- Compare the pressure at which the contacts opened to the desired cutout pressure.
- Adjust or replace the control as needed.

Relay and Contactors

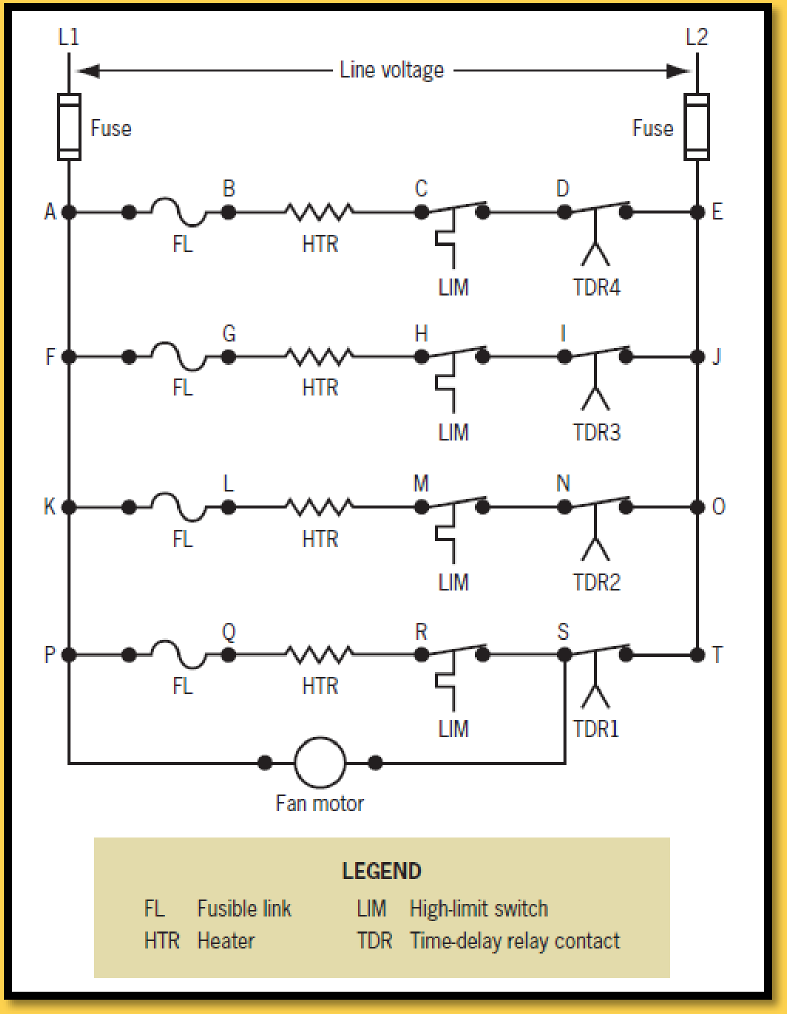
- Magnetic coil operates a set of contacts.
- Check coil:
  - Voltage; and
  - Resistance.
- Check contacts:
  - Resistance – power off; and
  - Voltage drop – load operating.



Voltage Drop Test for Relay and Contactor Coils

Electric Heaters

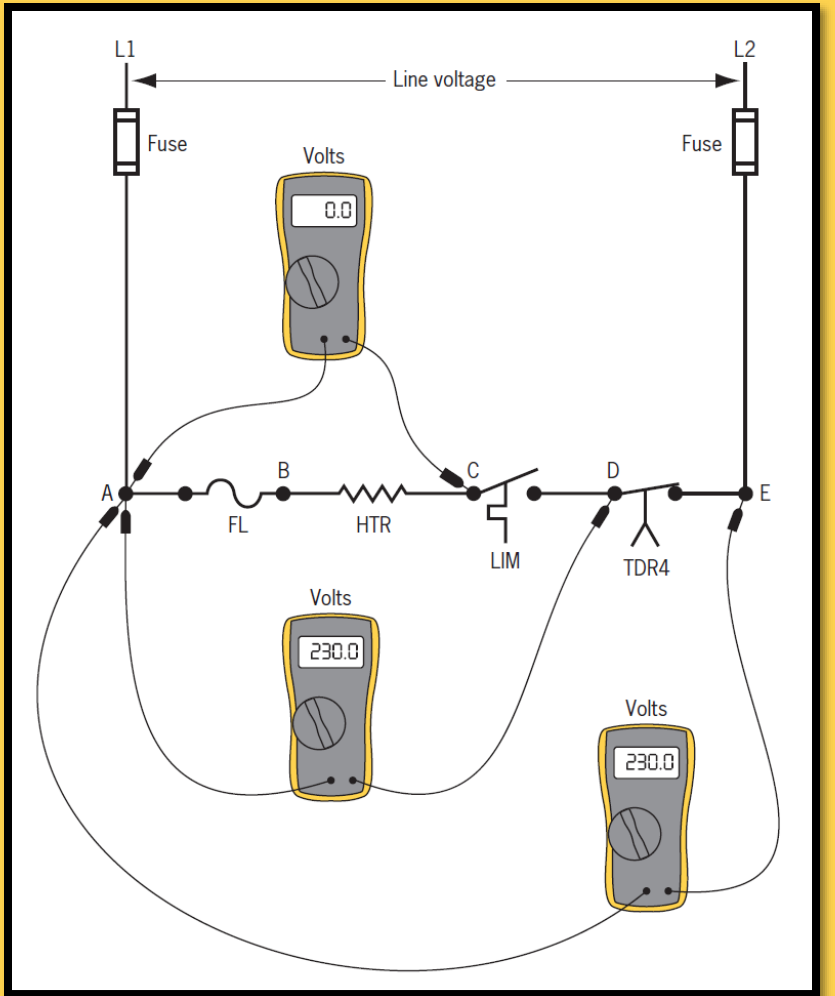
- Time-delay relay – sequencers.
- High limits.
- Fusible links.
- Main fuses.
- Air flow switches.
- Heaters should not glow red or orange:
  – Low air flow.



Typical Heater Package Circuit

Troubleshooting Open High-limit Switch

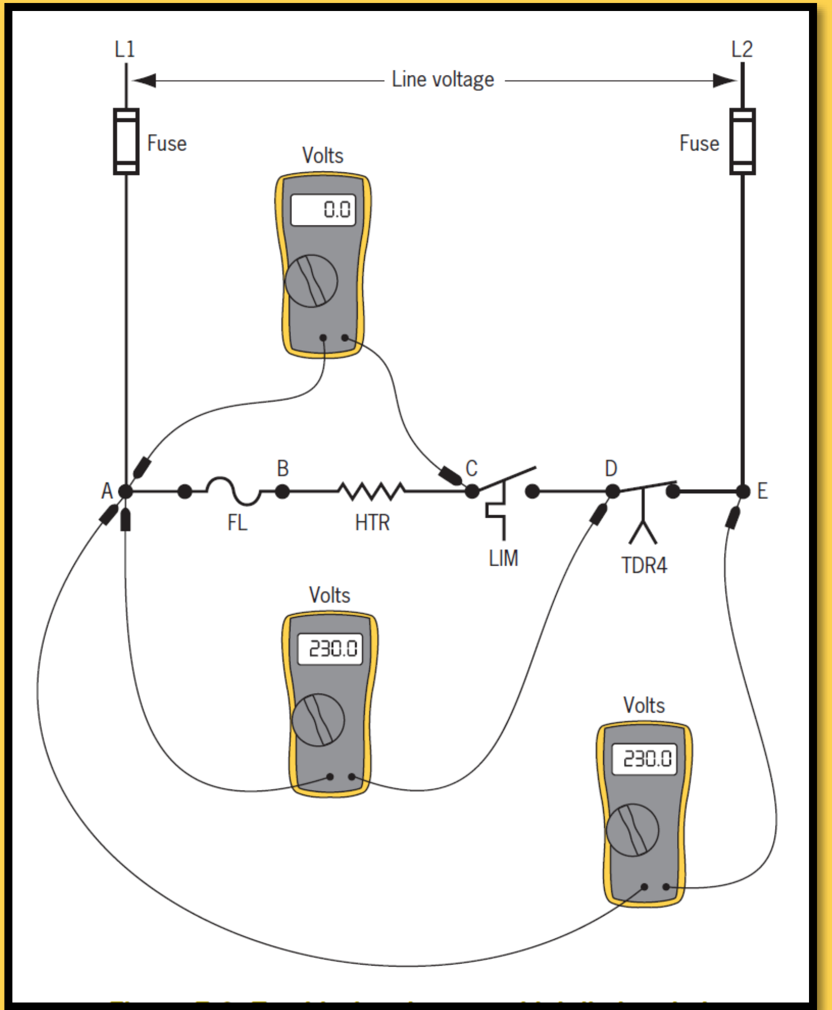
- Both line-voltage fuses are intact, since line voltage can be measured between points A and E.
- You also may conclude that the TDR4 contacts are closed, because line voltage is measured between points A and D.



Troubleshooting Open High-limit Switch

Troubleshooting Open High-limit Switch

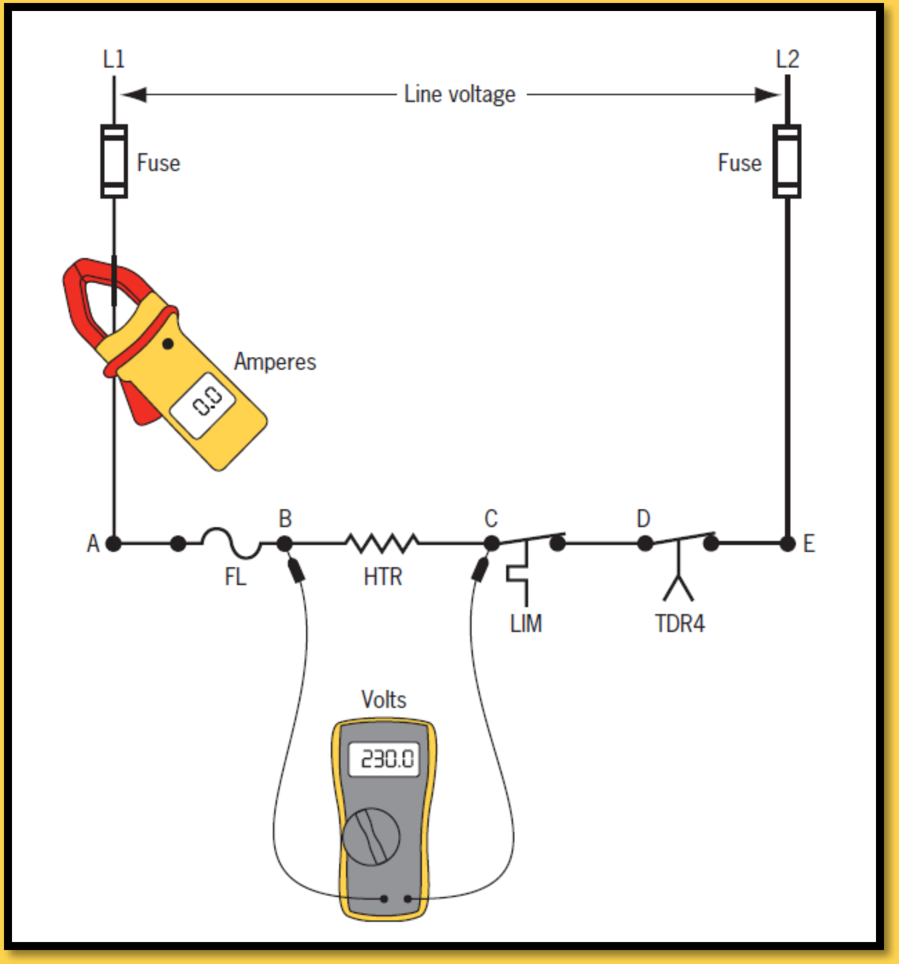
- The voltage reading of 0 V between points A and C indicates that the high-limit switch is open between points C and D.
- A voltage measurement taken between points C and D will read 230 V, thus confirming that the high-limit switch is open and the fusible link is intact.



Troubleshooting Open High-limit Switch

Electric Heaters

- Measuring voltage available to the heater.
- Measuring current draw of circuit:
  - If voltage is available to the heater with no current draw, the heater element is open.



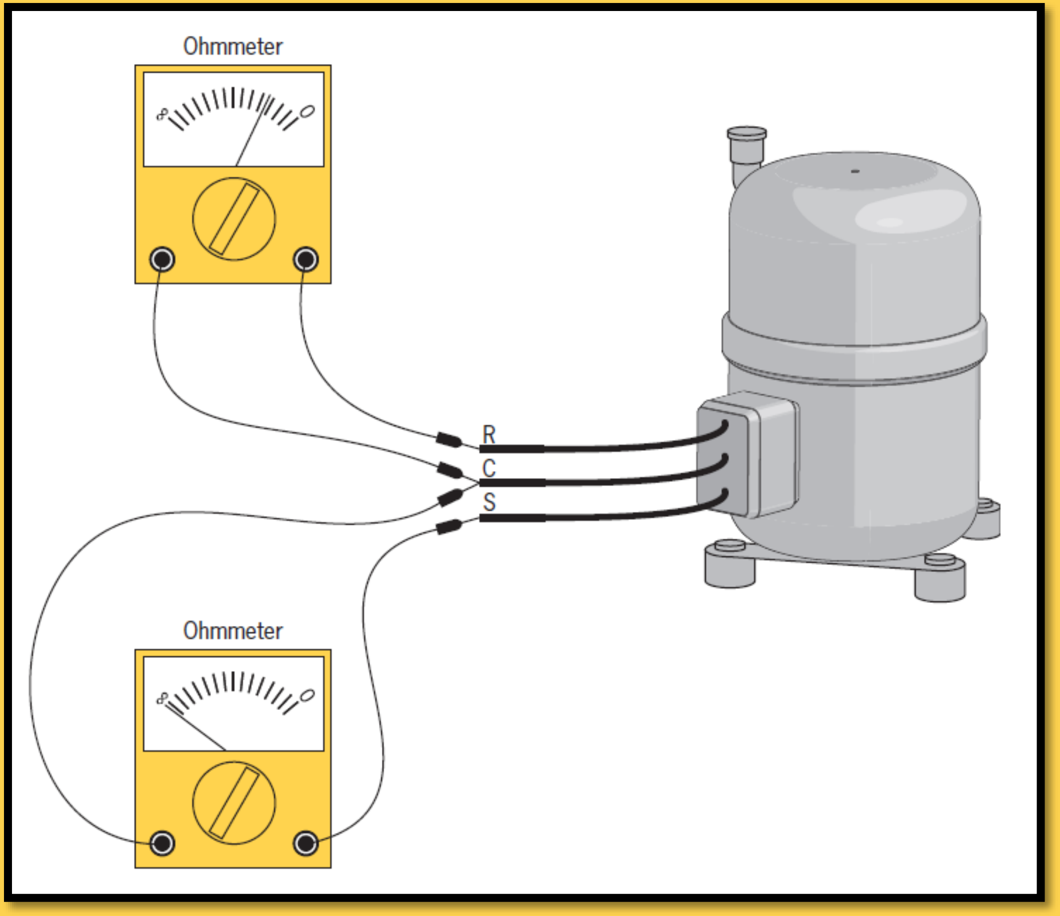
Troubleshooting Open Heater Element

Motors

- Check for proper voltage to the motor:
  - No load voltage; and
  - Starting voltage.
- Check resistance of start and run windings:
  - Opens, shorts and grounds; and
  - Check overload if both windings show open.
- Check capacitors.
- Check contactors (voltage drop).

Open Winding

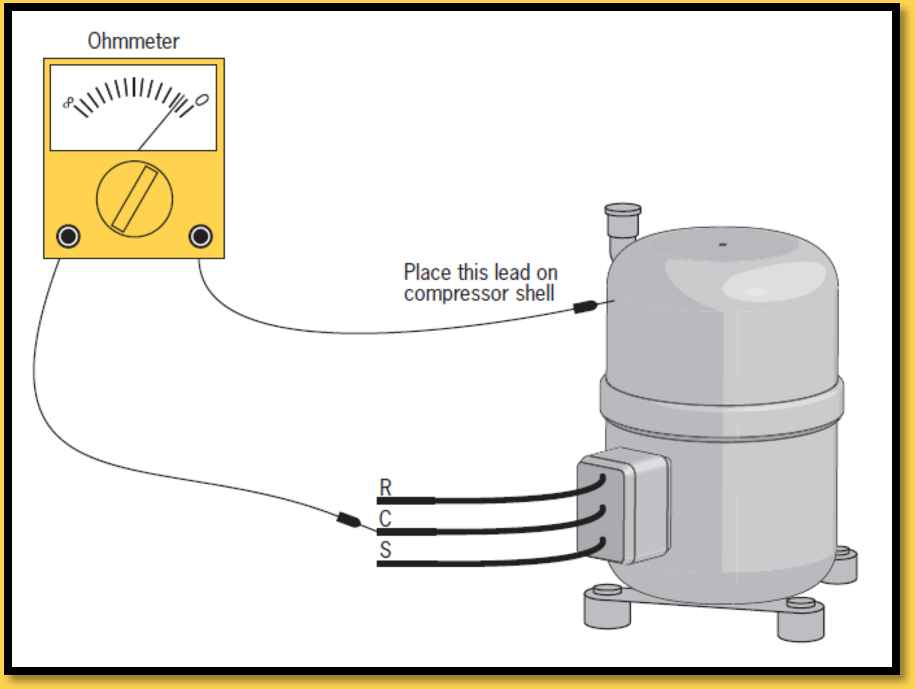
- Infinite resistance = open winding.
- Compressors have an internal overload between “R” and “C,” and “S” and “C”
  - Temperature activated, normally closed, opens on temperature rise.
- Windings also may be shorted.



Open Start Winding

Grounded Winding

- Winding breaks down and comes in contact with motor housing or metallic surface.
- POWER OFF and isolate motor.
- Set meter to high resistance and measure from all terminals to shell.
- Any measurable resistance indicates the motor is grounded.



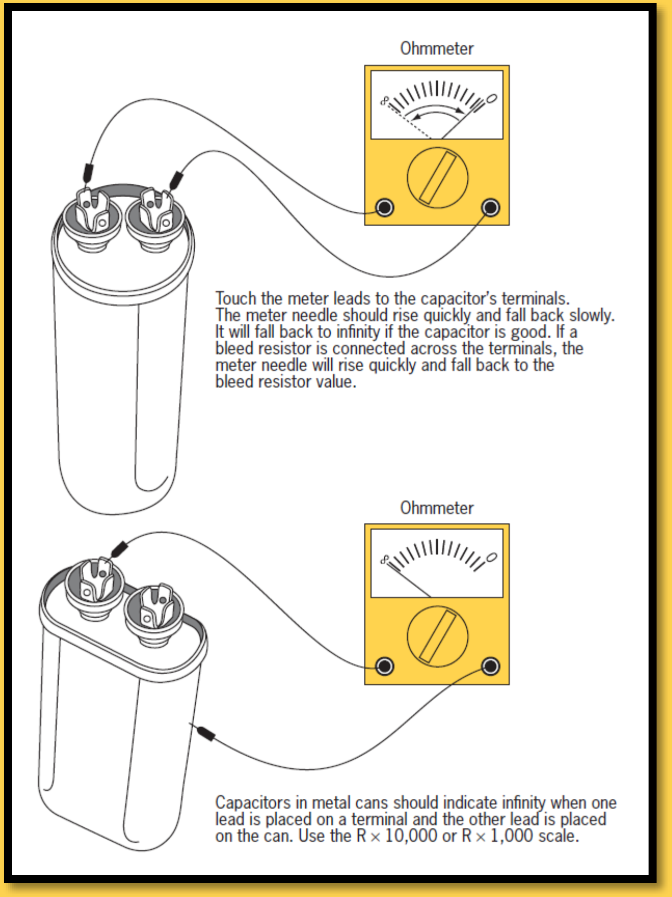
Grounded Motor Winding

Capacitors

- Disconnect and discharge capacitor with 20,000 ohm, 2 W resistor.
- Check with an ohmmeter:
  - Analog; or
  - Digital.
- Capacitance meter.

Capacitor Testing with Ohmmeter

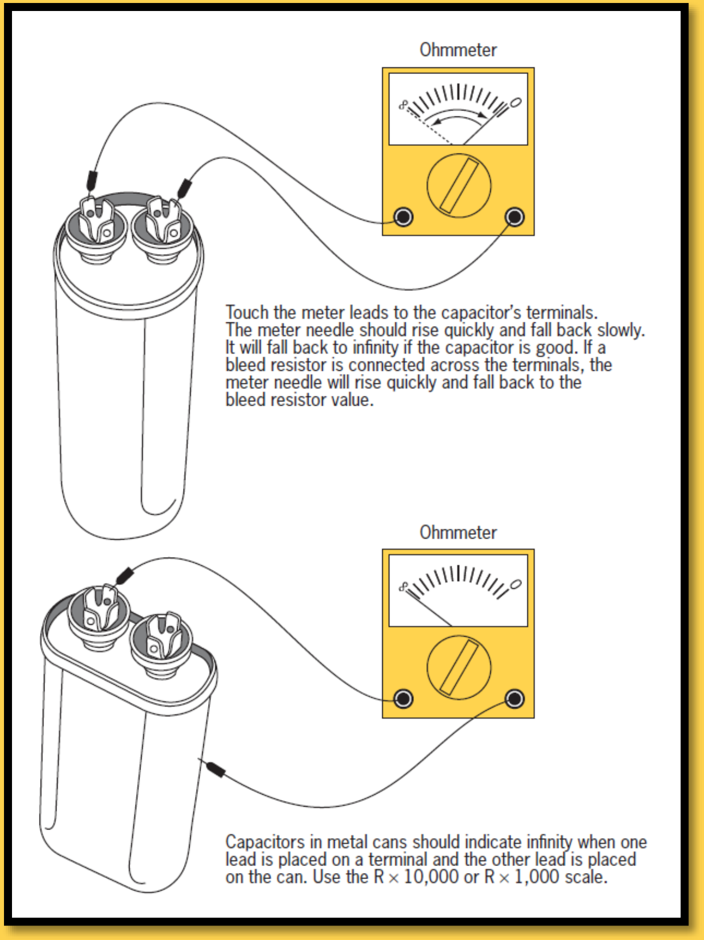
1. Carefully discharge the capacitor by placing a 20,000-Ω, 2-W resistor across the terminals for five seconds.
2. Remove the wiring from the capacitor, including bleed resistors if present. Make a note of the wire locations to enable you to re-install the capacitor properly.
3. Set the resistance range of your ohmmeter to the R × 1,000 or R × 100 range for start capacitors. For run capacitors, use the R × 1,000 or R × 10,000 range.
4. Touch your meter leads to the capacitor terminals.
5. If the capacitor is neither shorted nor open, the display will fall quickly toward 0 Ω and then return slowly toward infinity.



Capacitor Ohmmeter Test

Capacitor Testing with Ohmmeter

6. If the display indicates 0 Ω and remains there, the capacitor is shorted and must be replaced
7. If the display falls toward 0 Ω and then registers a measurable resistance, the capacitor has a partial short and must be replaced
8. You can re-test the capacitor by reversing the meter leads and repeating the process described above
9. Infinite resistance must be measured between the capacitor terminals and the casing. If continuity can be measured between a terminal and the casing, the capacitor must be replaced



Capacitor Ohmmeter Test

Capacitor Testing

- A meter like this one can also measure capacitance:
  - Discharge capacitor first as described.
- A start capacitor may be considered useable if its measured capacitance is equal to or up to 20% greater than the value printed on the capacitor.
- A run capacitor may be considered useable if its measured capacitance is ±10% of the rated value.

Reading Capacitance With Multimeter

Summary

- Electrical troubleshooting is a skill that every HVACR technician must develop.
- Employ the appropriate tool for the task at hand, and take measurements with your instrument set to the appropriate scale.
- You must understand how a system is designed to operate.
- You must know the sequence of operation for the equipment used in the system:
  - Only then can you make a judgment about whether the observed performance is correct or not.
- Utilize the manufacturer’s wiring diagrams.

System Performance Checks

Chapter 8

Lesson Objectives

- Understand:
  - Laws of heat transfer;
  - The importance of proper air distribution and air flow;
  - Air flow measurement;
  - Causes of low air flow;
  - The use of manufacturers data for system checks;
  - Proper evacuation, leak testing and charging; and
  - The proper approach to a service call.

Introduction

- You’re in the business of heat transfer.
- Refrigerants changing state makes this possible.
- Refrigerants evaporate and absorb heat.
- Refrigerants condense and reject heat.

Laws of Physics

- Heat moves from hot to cold.
- Boiling point is dependant on pressure:
  - Use temperature-pressure chart for refrigerants;
  - Sample shown here; and
  - Detailed chart is shown on the next slide.

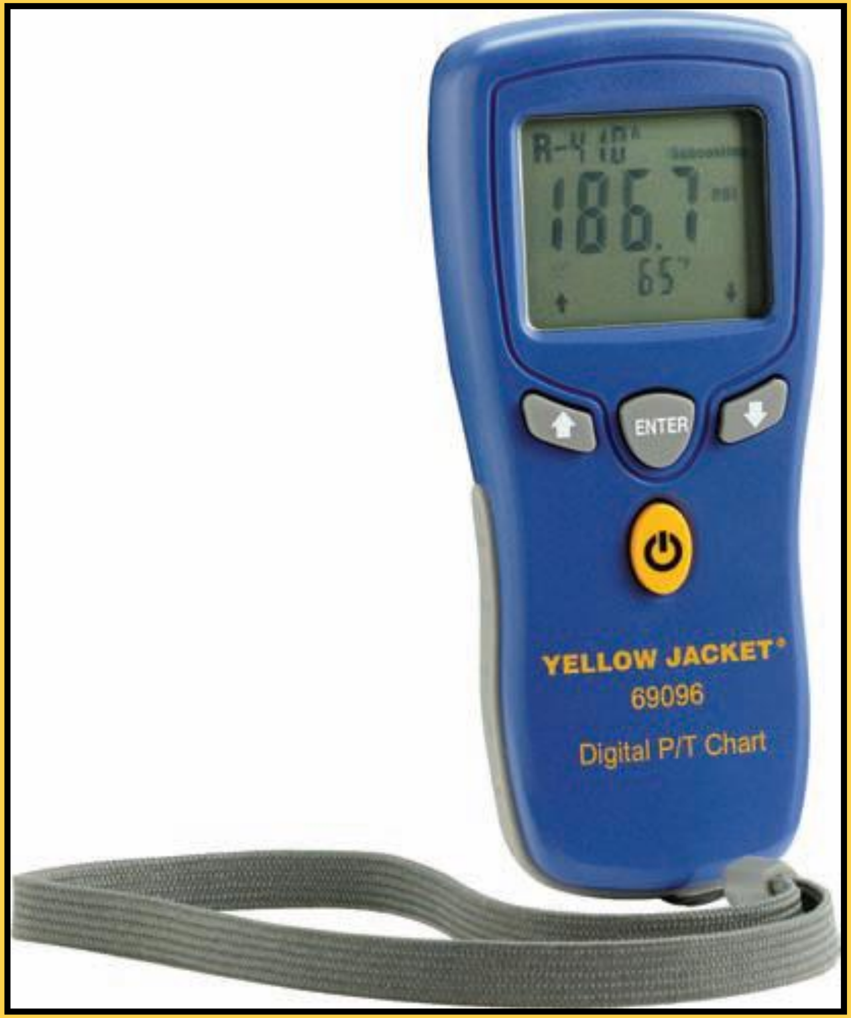
Temperature (°F)	Pressure, psig	
	R-410A	R-22
41	120	70
42	123	72
43	125	73
44	127	75
45	130	76
108	354	220
112	374	233
116	395	246
118	406	253

Pressure-temperature Table

Temp, °F	Pressure, psig		Temp, °F	Pressure, psig		Temp, °F	Pressure, psig	
	R-410A	R-22		R-410A	R-22		R-410A	R-22
–40	10.8	0.6	10	62.2	32.8	60	169.6	101.6
–39	11.5	1.0	11	63.7	33.8	62	175.4	105.4
–38	12.1	1.4	12	65.2	34.8	64	181.5	109.3
–37	12.8	1.8	13	66.8	35.8	66	187.6	113.2
–36	13.5	2.2	14	68.3	36.8	68	193.9	117.3
–35	14.2	2.6	15	69.9	37.8	70	200.4	121.4
–34	14.9	3.1	16	71.5	38.8	72	207.0	125.7
–33	15.6	3.5	17	73.2	39.9	74	213.7	130.0
–32	16.3	4.0	18	74.9	40.9	76	220.6	134.5
–31	17.1	4.5	19	76.6	42.0	78	227.7	139.0
–30	17.8	4.9	20	78.3	43.1	80	234.9	143.6
–29	18.6	5.4	21	80.0	44.2	82	242.3	148.4
–28	19.4	5.9	22	81.8	45.3	84	249.8	153.2
–27	20.2	6.4	23	83.6	46.5	86	257.5	158.2
–26	21.1	6.9	24	85.4	47.6	88	265.4	163.2
–25	21.9	7.4	25	87.2	48.8	90	273.5	168.4
–24	22.7	8.0	26	89.1	50.0	92	281.7	173.7
–23	23.6	8.5	27	91.0	51.2	94	290.1	179.1
–22	24.5	9.1	28	92.9	52.4	96	298.7	184.6
–21	25.4	9.6	29	94.9	53.7	98	307.5	190.2
–20	26.3	10.2	30	96.8	55.0	100	316.4	195.9
–19	27.2	10.8	31	98.8	56.2	102	325.6	201.8
–18	28.2	11.4	32	100.9	57.5	104	334.9	207.7
–17	29.2	12.0	33	102.9	58.8	106	344.4	213.8
–16	30.1	12.6	34	105.0	60.2	108	354.2	220.0
–15	31.1	13.2	35	107.1	61.5	110	364.1	226.4
–14	32.2	13.9	36	109.2	62.9	112	374.2	232.8
–13	33.2	14.5	37	111.4	64.3	114	384.6	239.4
–12	34.2	15.2	38	113.6	65.7	116	395.2	246.1
–11	35.3	15.9	39	115.8	67.1	118	405.9	253.0
–10	36.4	16.5	40	118.1	68.6	120	416.9	260.0
–9	37.5	17.2	41	120.3	70.0	122	428.2	267.1
–8	38.6	17.9	42	122.7	71.5	124	439.6	274.3
–7	39.8	18.7	43	125.0	73.0	126	451.3	281.7
–6	40.9	19.4	44	127.4	74.5	128	463.2	289.2
–5	42.1	20.1	45	129.8	76.1	130	475.4	296.9
–4	43.3	20.9	46	132.2	77.6	132	487.8	304.7
–3	44.5	21.7	47	134.7	79.2	134	500.5	312.6
–2	45.7	22.4	48	137.2	80.8	136	513.4	320.7
–1	47.0	23.2	49	139.7	82.4	138	526.6	329.0
0	48.3	24.0	50	142.2	84.1	140	540.1	337.4
1	49.6	24.9	51	144.8	85.7	142	553.9	345.9
2	50.9	25.7	52	147.4	87.4	144	567.9	354.6
3	52.2	26.5	53	150.1	89.1	146	582.3	363.5
4	53.6	27.4	54	152.8	90.8	148	596.9	372.5
5	55.0	28.3	55	155.5	92.6	150	611.9	381.7
6	56.3	29.2	56	158.2	94.4			
7	57.8	30.1	57	161.0	96.1			
8	59.2	31.0	58	163.8	98.0			
9	60.7	31.9	59	166.7	99.8			

Pressure-temperature Charts

- Electronic pressure-temperature charts have become available in recent years.



Air Distribution

- Low airflow or air that is too cold may not provide enough heat to boil all of the refrigerant:
  - Liquid refrigerant reaches the compressor.
- Too much airflow or air that is too warm may increase the load on the compressor and reduce dehumidification.

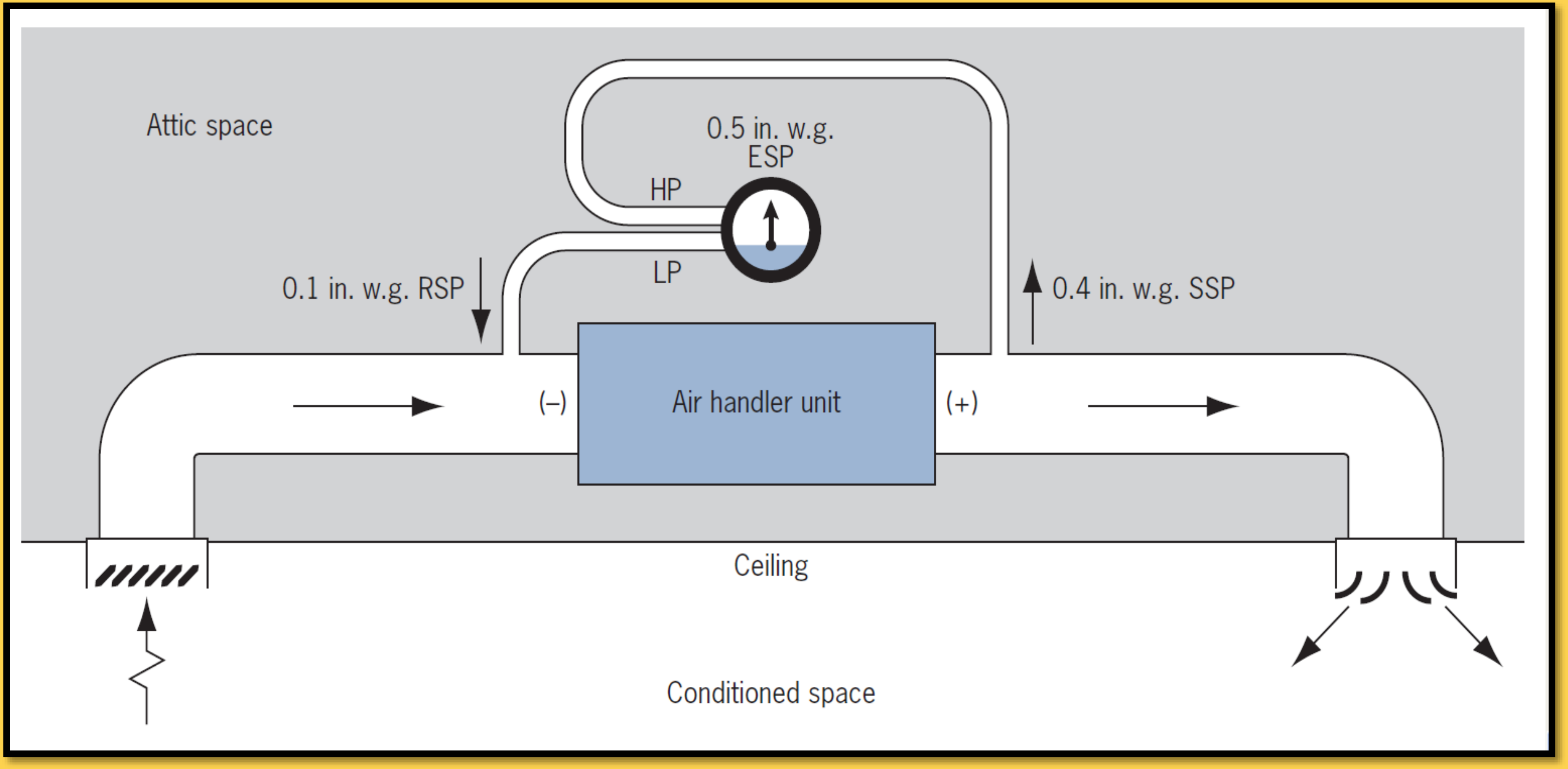
Airflow

- 400 CFM/ton:
  - Typical A/C.
- 450 CFM/ton:
  - Typical heat pump;
  - High sensible heat.
- 350 CFM/ton:
  - Higher levels of outdoor air;
  - High latent loads (dehumidification).

Airflow Measurement

- External Static Pressure:
  - Compare to manufacturers' tables;
  - Measured with a "diaphragm-type" pressure gauge:
    - "Magnehelic"; or
    - Electronic.
- Static pressure.
- Velocity pressure .
- Diagram on next page.

External Static Pressure Measurement



Blower Performance Data

Air flow, cfm	External static pressure (in. w.g.)											
	Vertical*						Horizontal**					
	230 V			208 V			230 V			208 V		
	HI	MED	LO	HI	MED	LO	HI	MED	LO	HI	MED	LO
500						0.55						
550						0.51						0.60
600					0.67	0.41						0.58
650			0.54		0.60	0.23			0.60			0.51
700			0.53		0.52	0.00			0.57		0.51	0.47
750		0.48	0.44	0.65	0.41			0.54	0.53		0.48	0.35
800	0.52	0.47	0.27	0.59	0.30		0.60	0.52	0.46	0.59	0.41	0.05
850	0.50	0.41	0.00	0.52	0.10		0.57	0.47	0.32	0.55	0.32	
900	0.47	0.30		0.42	0.01		0.54	0.40	0.03	0.52	0.21	
950	0.41	0.15		0.29			0.49	0.31		0.45	02	
1000	0.33	0.00		0.14			0.41	0.19		0.33		
1050	0.22			0.00			0.32	0.04		0.19		
1100	0.10						0.23			0.00		
1150	0.00						0.12					
1200							0.02					

* Vertical installation: With filter, no horizontal drip tray. Small apex baffle. Subtract 0.06 in. w.g. for downflow.
** Horizontal installation: As shipped, but without filter. Subtract 0.05 in. w.g. for horizontal left.

Airflow Measurement

- Temperature-rise method.
- Calculate Btus from electric heater:
  - Amps X volts X 3.413 Btus/watt = Btus.
  - For gas, clock meter to calculate input X efficiency.
- Measure temperature difference between supply and return:
  - Use one thermometer; and
  - Be out of the line-of-sight of the heater.
- CFM = Btus ÷ (TR X 1.08).

Air Flow Measurement

- Velocity pressure.
- Measure velocity pressure with a Pitot tube using a duct traverse.
- Velocity $= \mathbf{4005}\sqrt{\boldsymbol{velocity\ pressure}}$
- Cfm = velocity X area of duct in square feet.

Duct Design

- Proper duct design prevents high pressure drops that cause low airflow:
  - Use ACCA *Residential Duct Systems Manual D*;
  - Registers and diffusers—face velocity of no more than 700 ft/min;
  - Supply trunks 700 ft/min (900 max);
    - Branch 600 ft/min.
  - Return trunks 600ft/min (700 max);
    - Branch 400 ft/min.
  - Return grill face velocity 500 ft/min max; and
  - Filter grill 300 ft/min max.

Velocity Recommendations

	Supply side				Return side			
	Recommended		Maximum		Recommended		Maximum	
	Rigid	Flex	Rigid	Flex	Rigid	Flex	Rigid	Flex
Trunk ducts	700	600	900	700	600	600	700	700
Branch ducts	600	600	900	700	400	400	700	700
Supply outlet face velocity	Size for throw		700		—		—	
Return grille face velocity	—		—		—		500	
Filter grille face velocity	—		—		—		300	

Causes of Low Air Flow

- Duct systems;
- Dirty air filters;
- Dirty coils;
- Closed or restricted diffusers;
- Blower:
  - Wrong speed tap;
  - Bearing wear;
  - Low voltage; and
  - Dirty fan blades.

Heat-pump Air Flow

- Low airflow will also effect the heat pump in the heating mode:
  - High head pressure;
  - Lower heat output; and
  - Higher operating costs.

Air Balance

- Must have correct total airflow.
- Each room must have the correct airflow to provide even temperatures.
- Refrigeration cycle components may fail due to improper airflow.

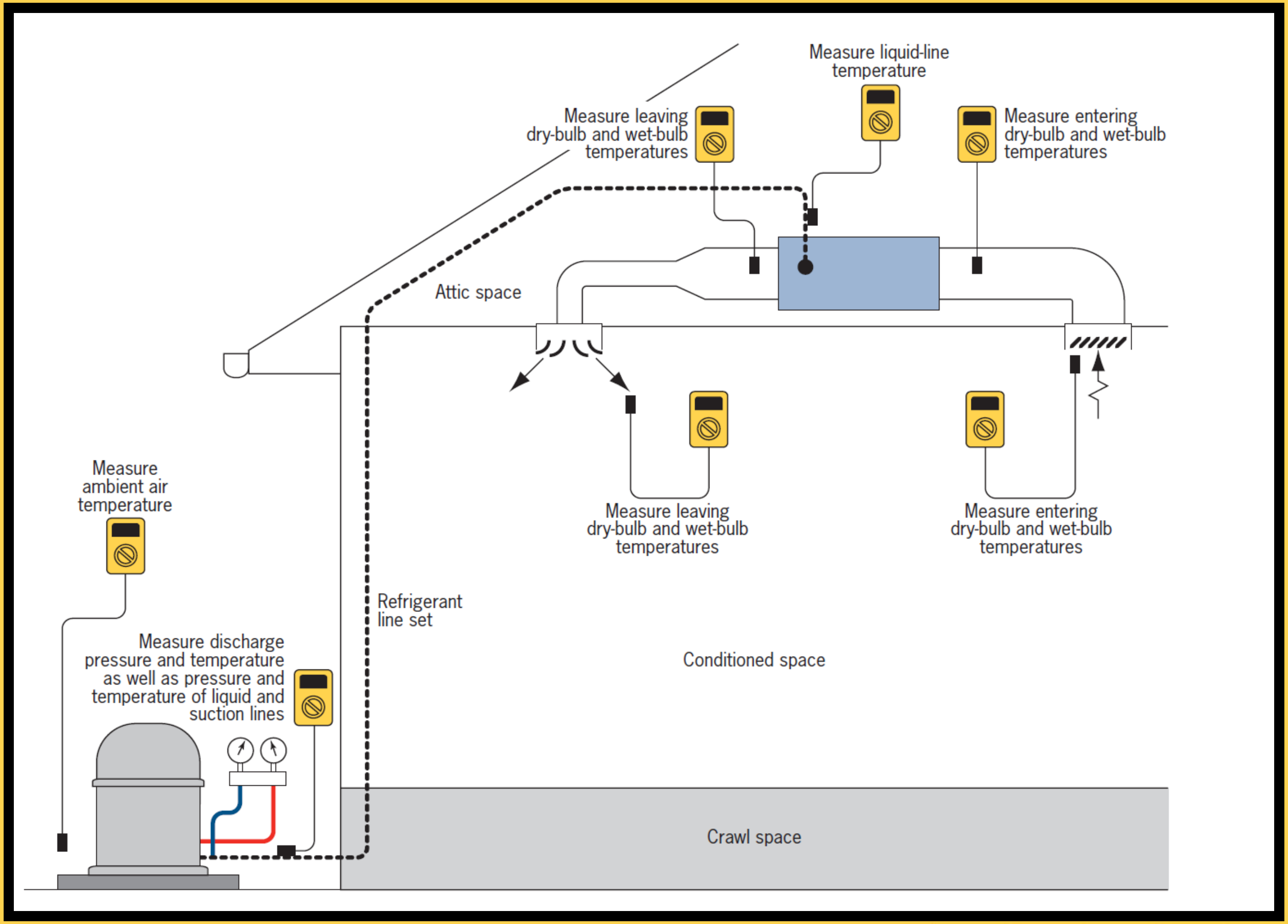
Base Line Data

- Outdoor temperature.
- Return-air wet- and dry-bulb temperatures:
  - At the return grille; and
  - Entering the cooling coil.
- Supply-air wet- and dry-bulb temperatures:
  - Leaving the evaporator coil; and
  - Leaving the supply outlet.

Base Line Data

- High-side pressure.
- Low-side pressure.
- Superheat:
  - Evaporator outlet; and
  - Compressor inlet.
- Subcooling:
  - Condenser outlet; and
  - Metering-device inlet.
- Compressor discharge temperature.

Data Collection Points



Manufacturer Data

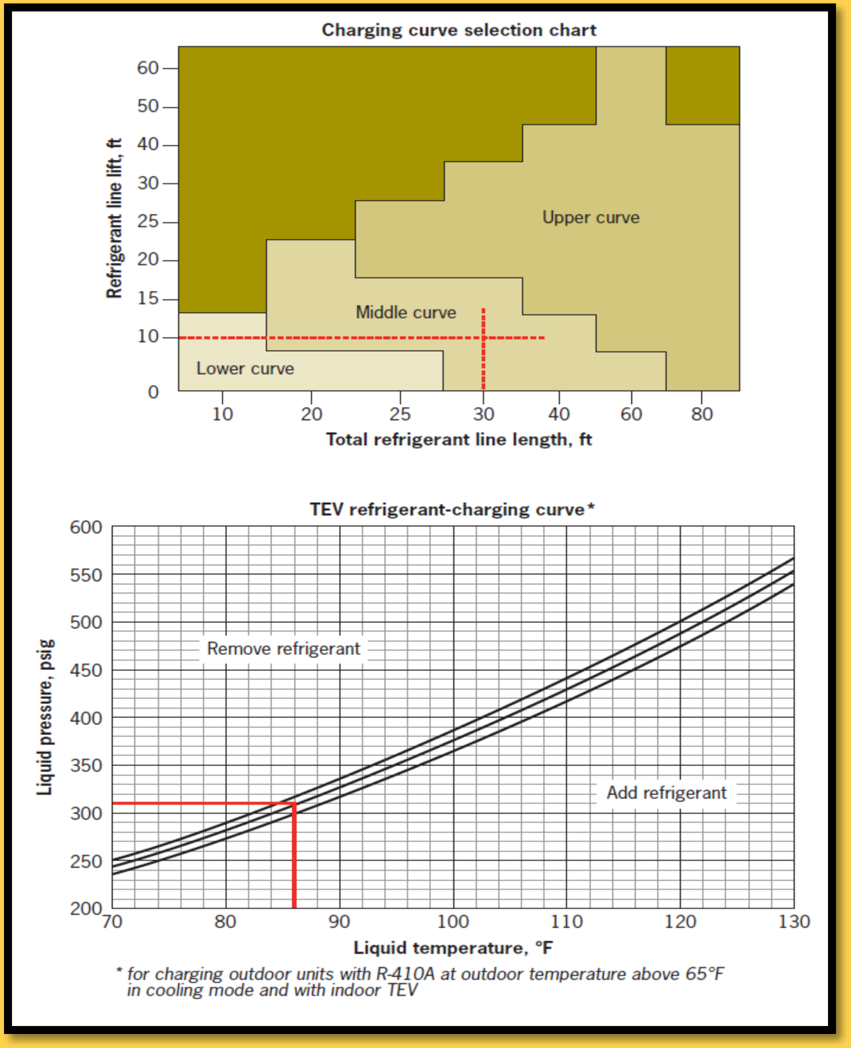
- Compare the measured data to the manufacturer's charts.
- Proper charge:
  - Superheat – fixed metering devices; and
  - Subcooling – TEV.
- Sample on next slide.

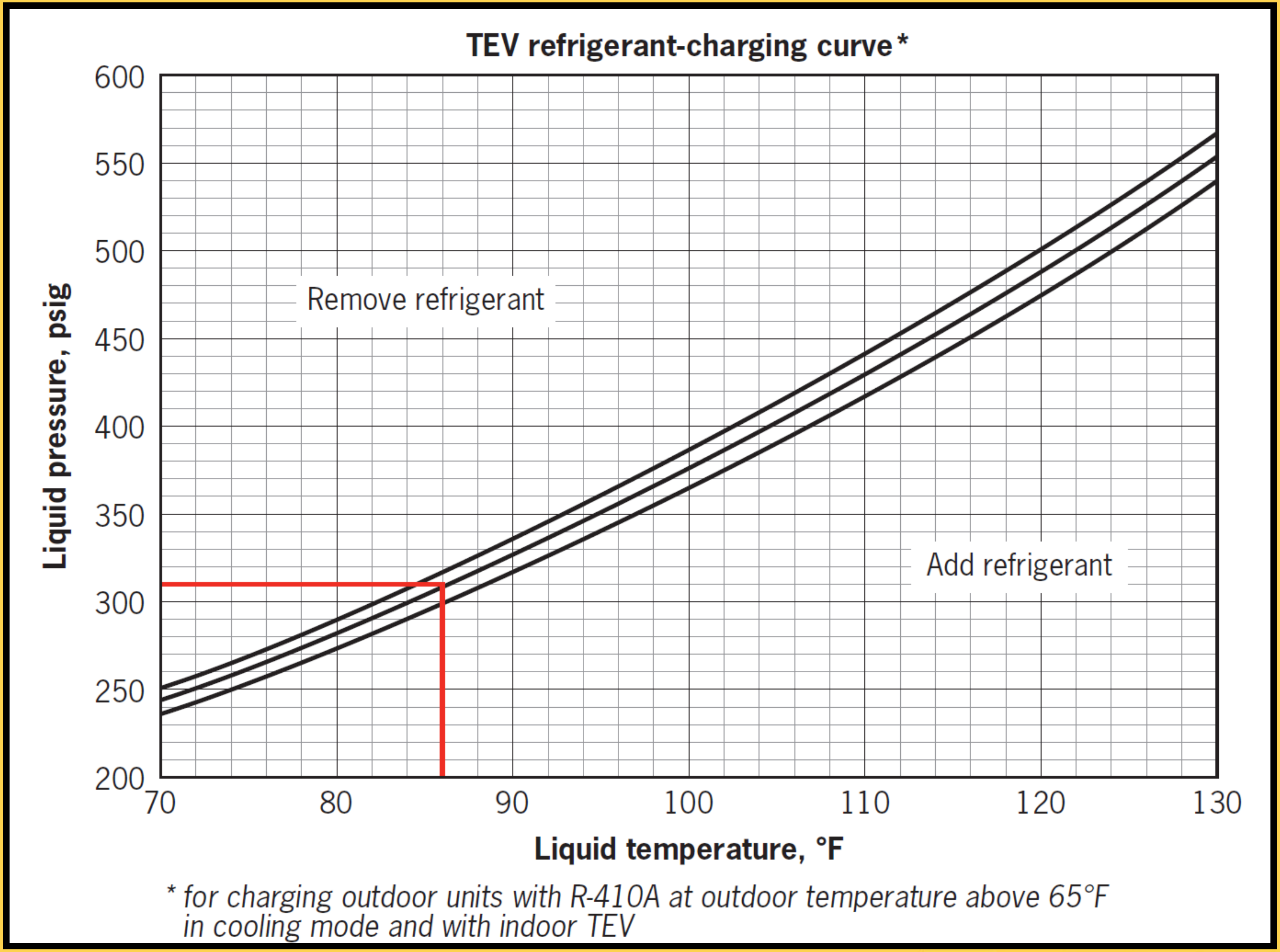
Temperature-pressure Chart

	Pressure, psig			Pressure, psig			Pressure, psig	
Temp, °F	R-410A	R-22	Temp, °F	R-410A	R-22	Temp, °F	R-410A	R-22
–40	10.8	0.6	10	62.2	32.8	60	169.6	101.6
–39	11.5	1.0	11	63.7	33.8	62	175.4	105.4
–38	12.1	1.4	12	65.2	34.8	64	181.5	109.3
–37	12.8	1.8	13	66.8	35.8	66	187.6	113.2
–36	13.5	2.2	14	68.3	36.8	68	193.9	117.3
–35	14.2	2.6	15	69.9	37.8	70	200.4	121.4
–34	14.9	3.1	16	71.5	38.8	72	207.0	125.7
–33	15.6	3.5	17	73.2	39.9	74	213.7	130.0
–32	16.3	4.0	18	74.9	40.9	76	220.6	134.5
–31	17.1	4.5	19	76.6	42.0	78	227.7	139.0
–30	17.8	4.9	20	78.3	43.1	80	234.9	143.6
–29	18.6	5.4	21	80.0	44.2	82	242.3	148.4
–28	19.4	5.9	22	81.8	45.3	84	249.8	153.2
–27	20.2	6.4	23	83.6	46.5	86	257.5	158.2
–26	21.1	6.9	24	85.4	47.6	88	265.4	163.2
–25	21.9	7.4	25	87.2	48.8	90	273.5	168.4
–24	22.7	8.0	26	89.1	50.0	92	281.7	173.7
–23	23.6	8.5	27	91.0	51.2	94	290.1	179.1
–22	24.5	9.1	28	92.9	52.4	96	298.7	184.6
–21	25.4	9.6	29	94.9	53.7	98	307.5	190.2
–20	26.3	10.2	30	96.8	55.0	100	316.4	195.9
–19	27.2	10.8	31	98.8	56.2	102	325.6	201.8
–18	28.2	11.4	32	100.9	57.5	104	334.9	207.7
–17	29.2	12.0	33	102.9	58.8	106	344.4	213.8
–16	30.1	12.6	34	105.0	60.2	108	354.2	220.0
–15	31.1	13.2	35	107.1	61.5	110	364.1	226.4
–14	32.2	13.9	36	109.2	62.9	112	374.2	232.8
–13	33.2	14.5	37	111.4	64.3	114	384.6	239.4
–12	34.2	15.2	38	113.6	65.7	116	395.2	246.1
–11	35.3	15.9	39	115.8	67.1	118	405.9	253.0
–10	36.4	16.5	40	118.1	68.6	120	416.9	260.0
–9	37.5	17.2	41	120.3	70.0	122	428.2	267.1
–8	38.6	17.9	42	122.7	71.5	124	439.6	274.3
–7	39.8	18.7	43	125.0	73.0	126	451.3	281.7
–6	40.9	19.4	44	127.4	74.5	128	463.2	289.2
–5	42.1	20.1	45	129.8	76.1	130	475.4	296.9
–4	43.3	20.9	46	132.2	77.6	132	487.8	304.7
–3	44.5	21.7	47	134.7	79.2	134	500.5	312.6
–2	45.7	22.4	48	137.2	80.8	136	513.4	320.7
–1	47.0	23.2	49	139.7	82.4	138	526.6	329.0
0	48.3	24.0	50	142.2	84.1	140	540.1	337.4
1	49.6	24.9	51	144.8	85.7	142	553.9	345.9
2	50.9	25.7	52	147.4	87.4	144	567.9	354.6
3	52.2	26.5	53	150.1	89.1	146	582.3	363.5
4	53.6	27.4	54	152.8	90.8	148	596.9	372.5
5	55.0	28.3	55	155.5	92.6	150	611.9	381.7
6	56.3	29.2	56	158.2	94.4			
7	57.8	30.1	57	161.0	96.1			
8	59.2	31.0	58	163.8	98.0			
9	60.7	31.9	59	166.7	99.8			

Using Charging Charts

- Measure liquid-line pressure and refrigerant temperature at liquid service valve.
- Find saturation point at 310 psig with temperature-pressure chart.
- Plot the points on the chart.
- Above the curve, remove refrigerant.
- Below curve, add refrigerant.
- Allow system to stabilize 20 minutes before additional measurements are made.

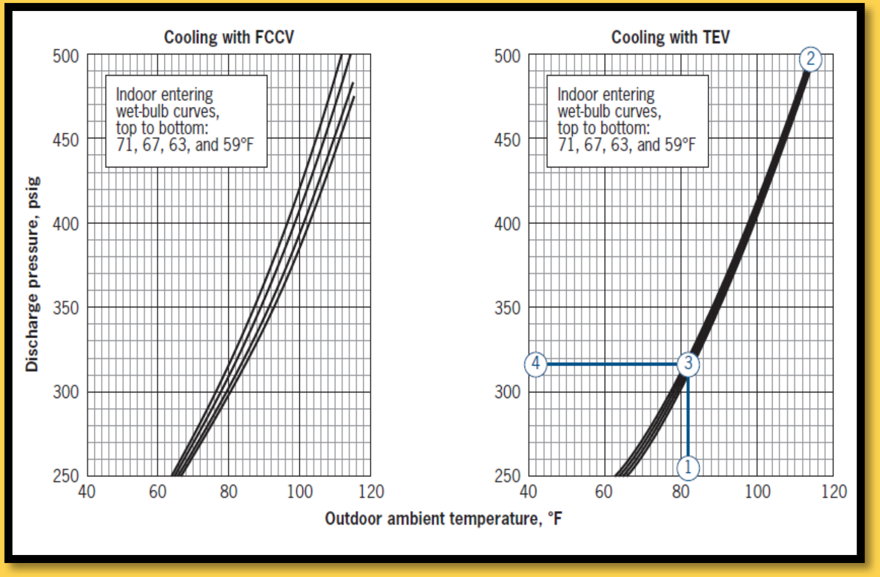



TEV refrigerant-charging curve*
Liquid pressure, psig
600
550
500
450
400
350
300
250
200
Remove refrigerant
Add refrigerant
70
80
90
100
110
120
130
Liquid temperature, °F
* for charging outdoor units with R-410A at outdoor temperature above 65°F in cooling mode and with indoor TEV

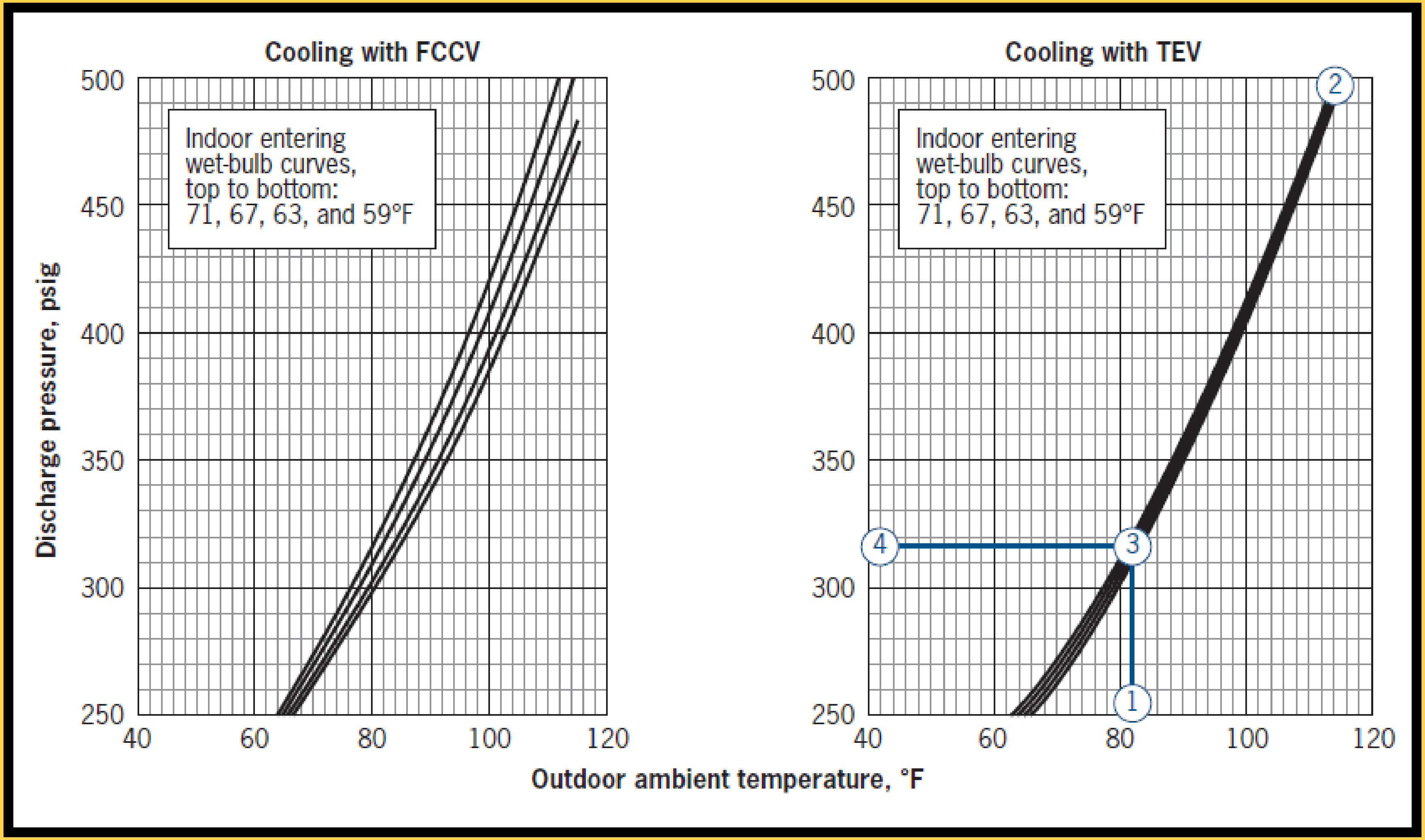
High-side Performance Graph

(Larger image on next page)

- Graph on left: fixed orifice.
- Graph on right: TEV.
- Outdoor temperature above 65°F.
- TXV example:
  - Locate outdoor air temp;
  - Locate indoor wet-bulb temperature;
  - Find the intersection;
  - Read the discharge pressure on the left of the graph; and
  - Discharge pressure should be +/- 10 psig.



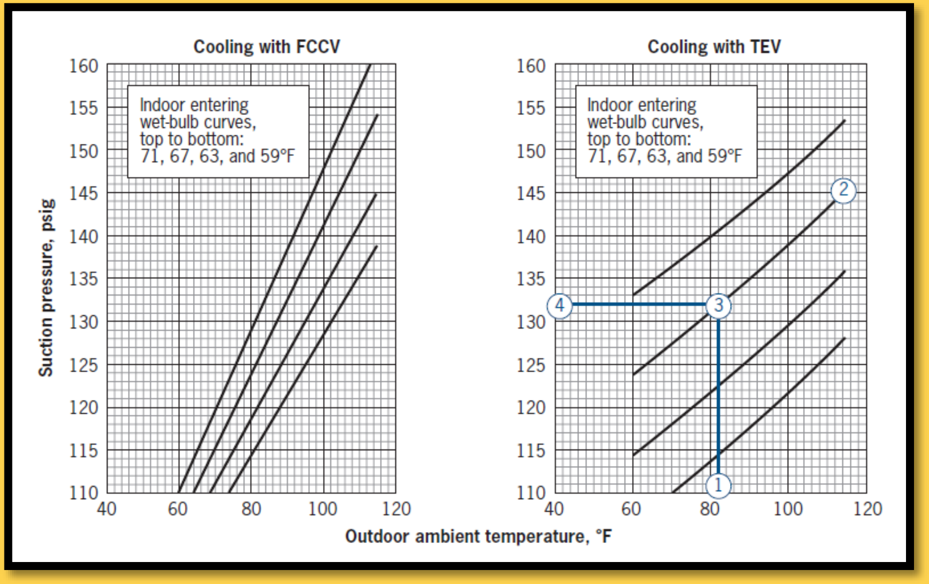
High-side performance graphs for R-410A system (cooling cycle)



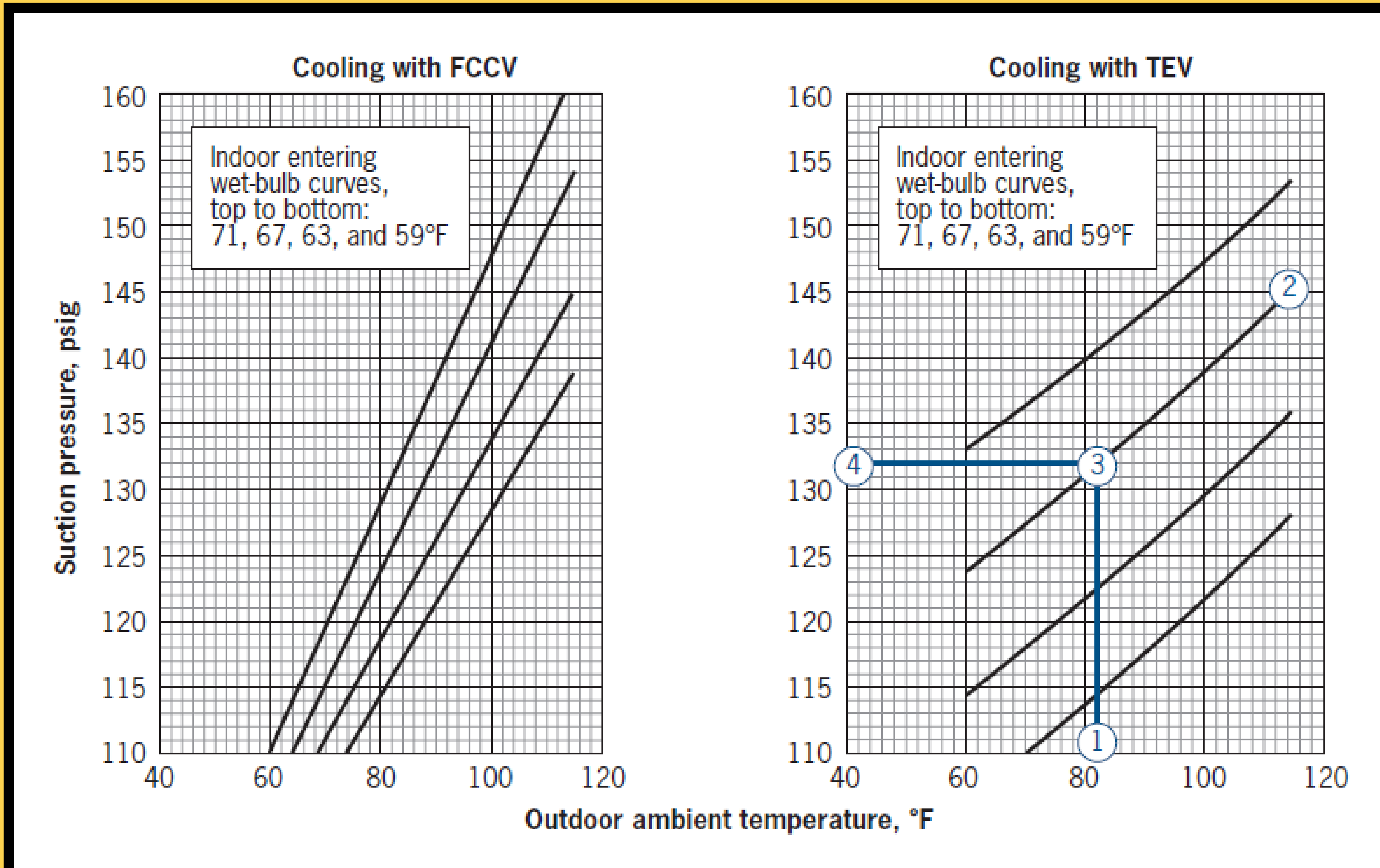
Low-side Performance Graph

(Larger image on next page)

- Graph on left: fixed orifice.
- Graph on right: TEV.
- Outdoor temperature above 65°F.
- TXV example:
  - Locate outdoor air temperature;
  - Locate indoor wet-bulb temperature;
  - Find the intersection;
  - Read the suction pressure on the left of the graph;
  - Discharge pressure should be +/- 3 psig; and
  - 8°F–12°F degrees superheat for TEV system.
- Superheat must not drop below 5°F.



Low-side performance graphs for R-410A System (cooling cycle)



Superheat Values in ˚F for Systems Using Fixed Metering Devices

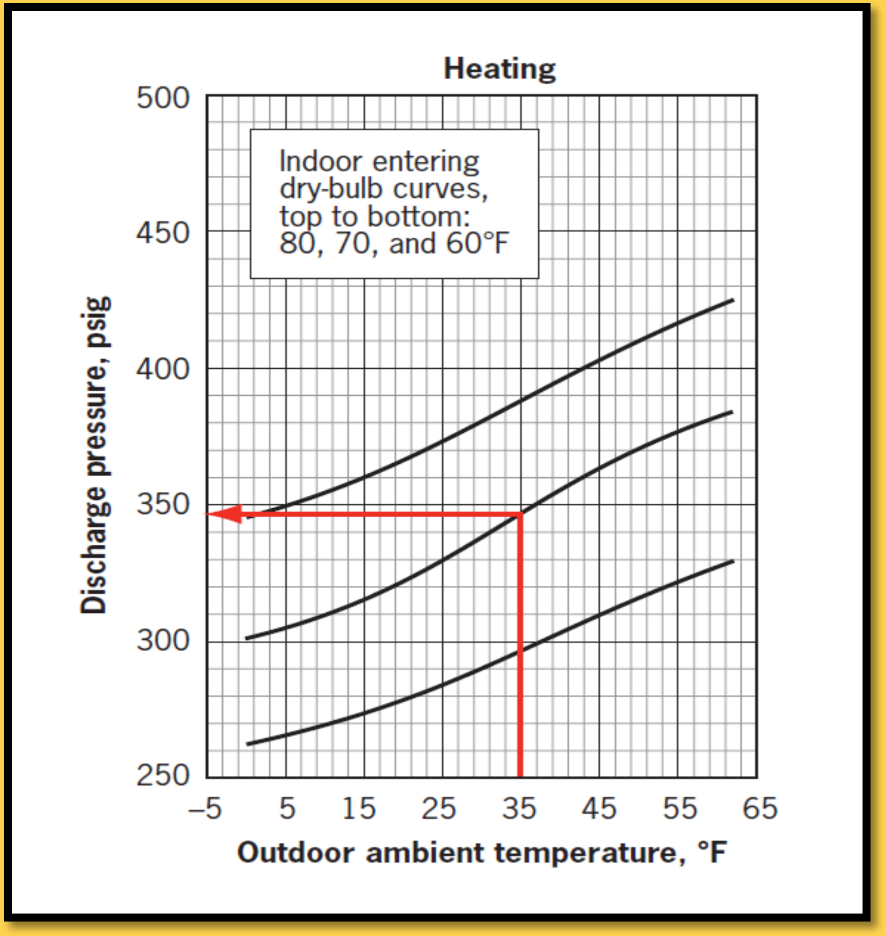
Entering air conditions			Outdoor air temperature, °F												
°F wb	°F db	%RH	55	60	65	70	75	80	85	90	95	100	105	110	115
	60	78	17	12	8	5									
	65	57	18	14	9	5									
56	70	41	19	15	10	5									
	75	29	21	18	11	7	5								
	80	20	22	18	14	9	5								
	60	89	22	18	13	9	5								
	65	67	23	18	14	9	5								
58	70	49	23	18	14	10	5								
	75	34	23	19	14	10	6	5							
	80	24	24	20	16	12	8	5							
	65	78	24	20	16	12	8	5							
	70	57	25	21	17	13	9	5							
60	75	41	26	22	18	14	10	8	5						
	80	30	27	23	19	15	12	8	5						
	85	21	28	25	21	17	14	10	6	5					
	65	85	26	21	17	13	9	8	7	5					
	70	64	27	24	20	16	12	8	7	5					
62	75	49	29	26	22	18	15	11	7	5					
	80	38	30	26	22	19	15	12	8	5					
	85	26	31	27	24	20	18	13	10	5	5				
	70	72	30	26	23	19	15	12	8	6	5				
	75	58	31	28	24	21	17	14	10	7	6				
64	80	42	32	29	25	22	19	16	13	9	6	5			
	85	31	33	30	26	23	20	17	13	10	7	5			
	90	24	34	31	27	24	21	18	14	11	8	5			
	70	81	32	29	26	22	19	15	12	11	7	5			
	75	63	33	29	26	23	20	18	13	13	10	7	5		
66	80	48	35	32	29	26	23	20	17	14	11	8	5		
	85	36	35	32	29	26	23	20	17	14	11	8	5		
	90	28	36	33	30	27	24	21	18	15	12	9	6	5	
	70	90	35	32	29	26	23	19	17	13	10	7	5	5	
	75	70	36	33	30	26	23	20	18	14	11	8	5	5	
68	80	54	36	34	31	28	25	23	20	17	14	12	9	6	5
	85	42	36	35	32	30	27	24	21	18	15	13	10	7	5
	90	32	39	36	33	31	28	25	22	19	17	14	11	8	5

Superheat Values in ˚F for Systems Using Fixed Metering Devices (continued)

Entering air conditions			Outdoor air temperature, °F												
°F wb	°F db	%RH	55	60	65	70	75	80	85	90	95	100	105	110	115
70	70	100	36	35	32	29	27	24	21	18	15	12	10	7	5
	75	79	38	36	33	30	27	24	21	19	18	13	10	7	5
	80	62	38	36	33	31	28	26	23	21	18	16	13	11	8
	85	48	41	38	36	33	30	28	25	23	20	18	15	13	10
	90	38	42	39	37	34	32	29	27	24	21	19	16	14	11
72	75	88	41	38	36	33	31	28	26	23	20	18	15	13	10
	80	68	41	38	36	34	31	29	27	24	22	20	17	15	13
	85	54	42	40	38	35	33	30	28	25	23	21	18	16	13
	90	42	43	40	38	35	33	30	29	26	24	21	19	17	14
	95	33	43	40	38	36	33	31	29	27	24	22	20	18	15
74	75	96	43	41	39	36	34	32	29	27	25	22	20	18	15
	80	76	43	41	39	37	35	32	30	28	26	24	22	19	18
	85	60	44	41	39	37	35	33	31	29	26	24	22	20	18
	90	48	44	42	40	38	35	33	31	29	26	24	22	20	18
	95	38	45	43	40	38	36	33	31	29	27	25	22	20	18
76	80	84	45	43	42	40	38	36	34	32	30	28	27	25	23
	85	67	46	44	42	41	39	37	35	33	31	29	27	25	23
	90	54	47	46	44	42	40	38	38	34	32	31	29	27	25
	95	43	49	47	45	43	41	40	38	36	34	32	31	29	27
78	80	92	48	46	44	43	41	39	38	36	34	33	31	29	27
	85	74	48	47	45	43	41	40	38	36	34	33	31	30	28
	90	59	50	48	47	45	44	42	41	39	37	36	34	33	31
	95	48	51	50	49	47	46	45	43	42	41	39	37	36	35
80	80	100	50	48	47	46	44	42	41	39	38	36	34	33	31
	85	80	50	49	47	46	44	43	41	40	39	37	36	34	33
	90	65	51	50	48	47	46	44	43	41	40	39	37	36	34
	95	53	53	51	50	49	47	46	44	43	41	40	39	37	36

The Heating Cycle: High-side

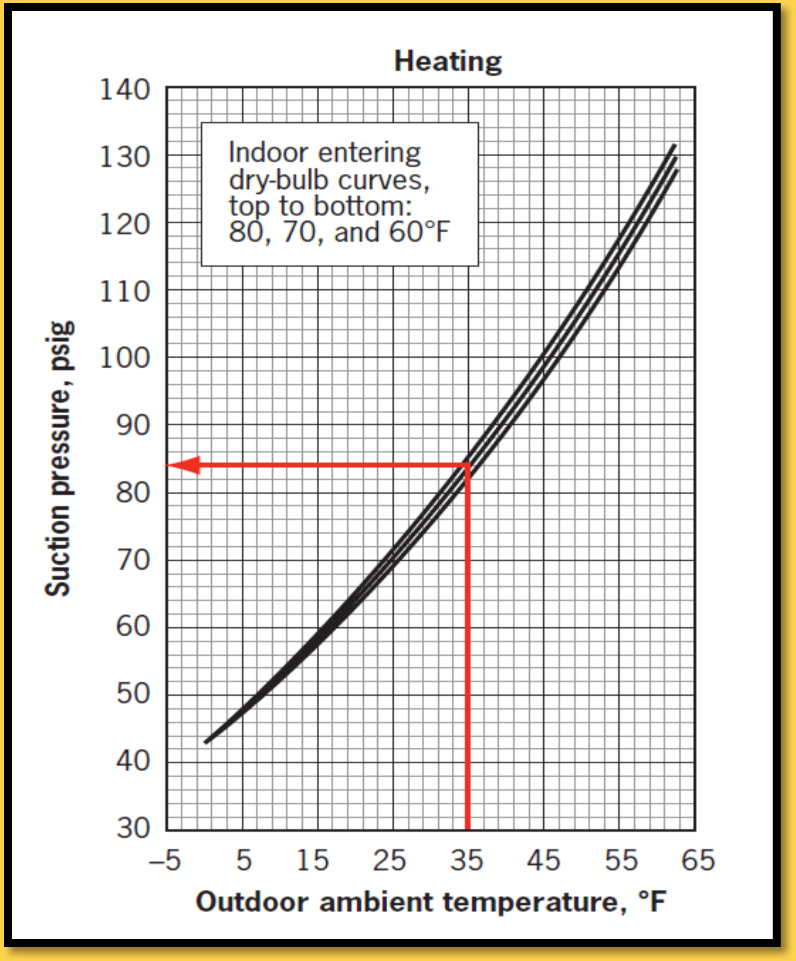
- Use manufacturer data.
- Measure outdoor ambient temperature.
- Measure temperature at indoor coil.
- Find intersection point and read discharge pressure to the left:
  - Should read +/- 10 psig.



Discharge Pressure Curves for R-410A System (heating cycle)

The Heating Cycle: Low-side

- Use manufacturer data.
- Measure outdoor ambient temperature.
- Measure temperature at indoor coil.
- Find intersection point and read suspection pressure to the left:
  - Should read ± 3 psig.



Suction Pressure Curves for R-410A System (Heating Cycle)

Refrigerant Circuit

- Start with a clean, dry and well-designed system:
  - Purge with nitrogen during brazing.
  - Evacuate system to at least 500 microns:
    - Water boils at -12°F at 500 microns.
  - Turn off pump and monitor vacuum level:
    - Rise to 1500–2500 microns indicates moisture; and
    - Rise above 2500 microns indicates leak.

Evacuation and Vacuum Pumps

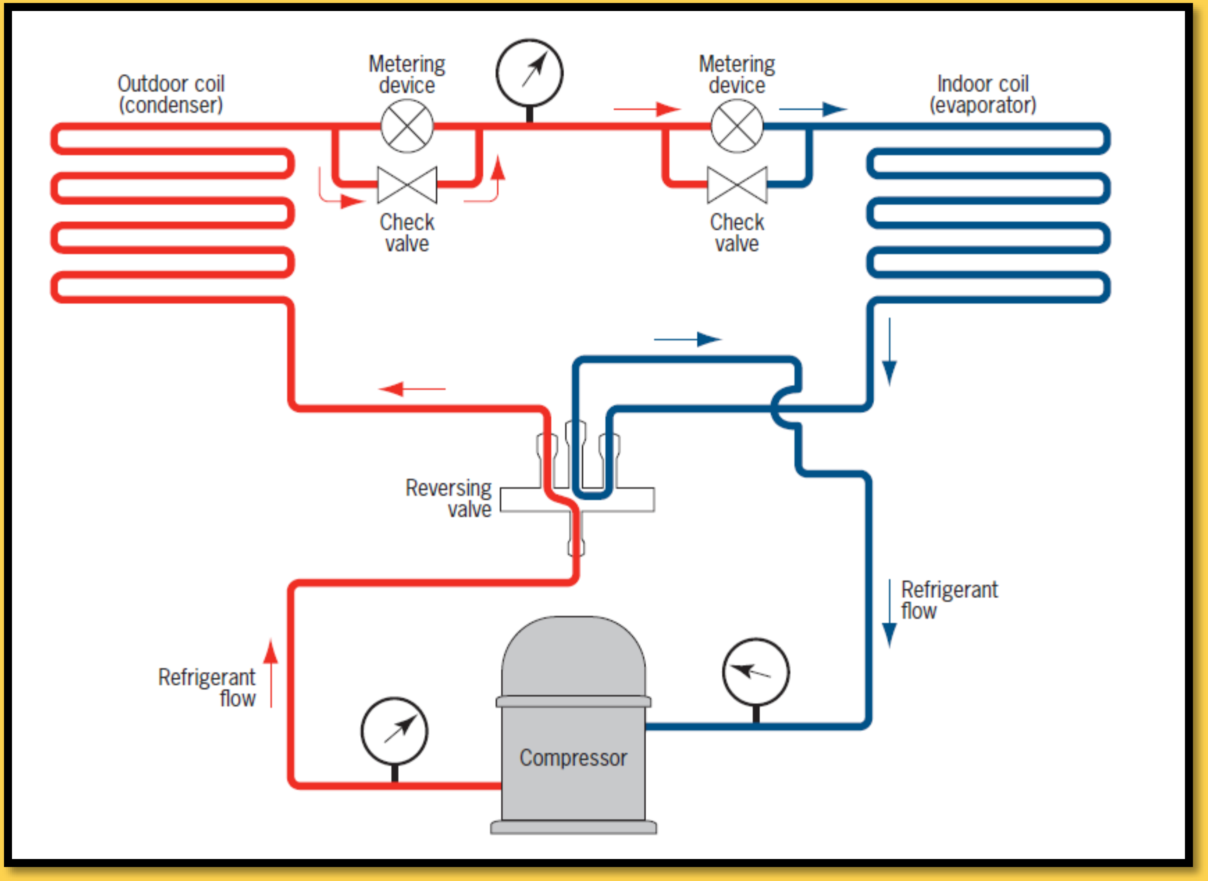
- Check oil level before starting.
- Change oil after each use.
- Proper gas ballast use reduces rate at which the oil absorbs moisture.
- When evacuation is complete, vale off the pump from the system and check micron level:
  - 2500 microns or less – water vapor remains; and
  - 2500 microns +++ - leak is present.

Leak Detection

- Pressurize with nitrogen.
- Vacuum test.
- Visual – oil traces.
- Leak detectors will locate the general area of the leak:
  - Electronic; and
  - Ultrasonic.
- Bubble solutions – don’t freeze or corrode copper.
- Dyes – do not over use:
  - Possible warranty issues – check with manufacturer.

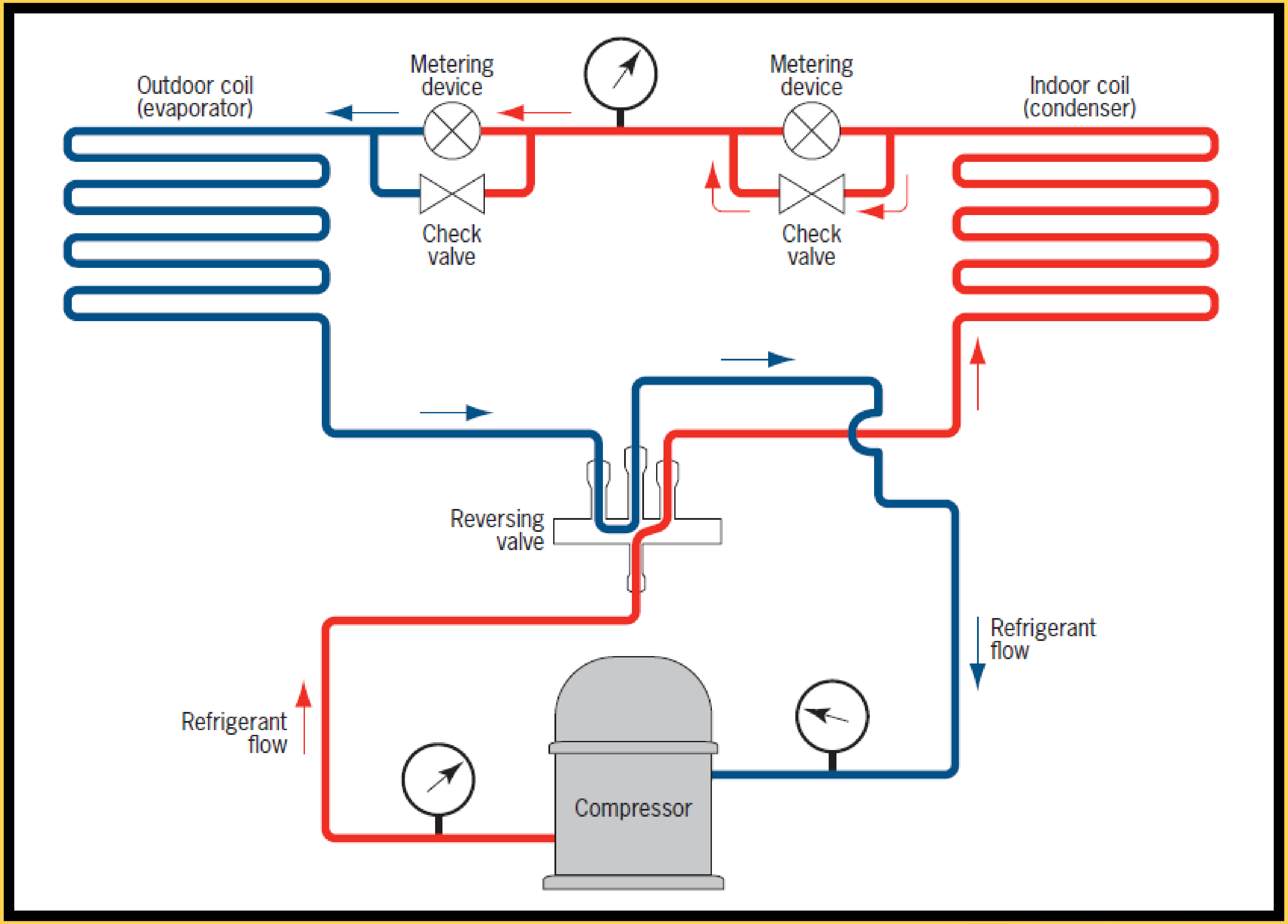
Refrigerant Circuit Components

- Compressor.
- Metering device.
- Reversing valve.
- Evaporator.
- Condenser.
- Accumulator (Not Shown).



Basic Heat Pump Cooling Cycle

Basic Heat-pump Heating Cycle



Metering Device

- Creates a pressure drop to allow refrigerant to boil at the needed temperature.
- Both fixed and TEV devices are used.
- Two devices are needed with a heat-pump system:
  - Used with check valves to allow flow to bypass the metering device when not in use. May be built into the metering device.
    - Leaking check valves can allow overfeeding of the evaporator.
    - Sticking check valves will cause excessive pressure drop.

Compressor

- It is possible to check the condition of the valves in a compressor used in a cooling system by closing the liquid-line service valve and pumping down the refrigerant circuit.
- If the suction pressure rises very rapidly, the compressor valves are defective:
  - This test is not definitive; and
  - If the compressor has two cylinders, it may still be able to pull and hold a vacuum, even if a valve in the other cylinder is faulty.

Compressor Burnout

- Compressor burnout is caused when the motor insulation fails and the winding shorts out.
- The excessive heat generated will produce acids and other contaminants in the oil.
- The system must be cleaned using proper filter driers or the contaminated oil will damage the new compressor:
  - R-22 Mineral oil; and
  - R-410A POE.

Low Ambient Operation

- When A/C systems need to operate at colder outside conditions measures must be taken to maintain sufficient head pressure.
- Insufficient head pressure will reduce refrigerant flow through the metering device or cause flashing in the liquid line.
- Head pressure control:
  – Fan cycling;
  – Fan speed control;
  – Dampers; and
  – Condenser flooding.

Accumulator

- An accumulator separates and holds liquid refrigerant from the suction line.
- May get some carryover in the suction line as a TEV hunts due to light or changing loads.
- May get some carryover in the suction line during defrost.

Brazing

- Purging with nitrogen during brazing is critical to prevent copper oxide inside the refrigeration system.
- Oil will carry the copper oxide through the system where it can plug TEVs, accumulators and filter driers, and settle in compressor:
  – POE oil is far less forgiving and will clean more of the copper oxide from the inside of the piping.

Understand the Components

- An understanding of the intended function of each of the primary refrigerant circuit devices makes it easier to evaluate the performance of the individual components.
- To evaluate any of these devices effectively, you must have a good grasp of the basic science behind the refrigeration cycle.
- When you have mastered the principles involved, you will better understand why each component is selected for a specific job.

Troubleshooting

- Talk with the customer.
- Verify the customer's complaint.
- Visually inspect the system.
- Isolate the fault.
- Correct the cause of the problem.
- Test system operation.
- Complete the service report/invoice.

Interview the Customer

- Important clues may be provided.
- Ask questions such as:
  – Can you describe the nature of the problem?
  – When was the last time your system was serviced?
  – When did you first notice a problem with your system?
  – Before you noticed the problem, was the system working OK?
  – Has your neighborhood experienced any recent power outages?

Verify the Customer's Complaint

- The customer is rarely a trained technician.
- The unit may be operating as expected:
  - Customer does not understand operation.
- Read between the lines.

Visually Inspect the Primary System Components

- Often exposes the cause of a fault.
- Start at the thermostat.
- Check indoor and outdoor components:
  - Oil on a refrigerant tubing joint indicates a leak.
- Check for debris.
- Clean indoor and outdoor coils.

Isolate the Fault

- If the condenser fan is running but the compressor is not, it is not necessary to check the outdoor breaker or fuses:
  - Investigate the circuit providing power to the compressor.

Correct the Cause of the Problem

- Safety first!
  - Remove jewelry and loose-fitting clothes;
  - Tie back long hair;
  - Wear the appropriate fire-rated clothing and use personal protective equipment (PPE)— e.g., safety glasses, impervious gloves, GFCIs, etc.; and
  - Disconnect power to the equipment when repairing or replacing defective components. Lock out and tag out whenever possible.
- Follow refrigerant handling guidelines.
- Respect the customer’s property.

Test the System Operation

- Operate the system for 20 minutes to achieve steady-state operation:
  – Complete paperwork during this time.
- All data points must be measured and evaluated:
  – Document on the service ticket.

Complete the Service Invoice

- Accuracy is important.
- Be detailed.
- Write legibly.
- Complete list of materials used.
- Have the customer sign the invoice.

Professionalism

- You may be the only direct contact the customer has with your company:
  - Make a professional impression.
- Leave the job site clean:
  - Judgments will be made on the area around the unit.
- Final step: explain the work performed in language the customer can understand.

Summary

- Problems may be misdiagnosed if principles are not understood.
- Use manufacturer data:
  - Including blower tables.
- Proper air flow is critical.
- Complete the job professionally.