MASSCEC HEAT PUMP & HVAC TRAINING NETWORK

Equipment Agnostic Lab Toolkit

Hands-On Skills Instructor Reference Guide

MARCH 2026

Developed by Technical Education Products, Inc.

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Introduction and Purpose

This Agnostic Lab Toolkit provides equipment-neutral hands-on lab outlines for the MassCEC Heat Pump & HVAC Training Network curriculum. It is designed to accompany the MassCEC Heat Pump Curriculum Map and serves as a flexible, turnkey resource that training programs can adapt to their specific equipment configurations.

Each lab follows a consistent framework: Required Components/Systems, Required Materials, Required PPE, Lesson Procedure (Background, Setup, Procedure, Closure, Assessment), Key Teaching Points, and Equipment Flexibility guidance. Rather than referencing proprietary training systems by brand or model number, this toolkit uses equipment category descriptions so that any training program can map skills to their available equipment.

Under the federal AIM Act, all new residential and light commercial HVAC systems now require A2L refrigerants such as R-454B. This toolkit integrates A2L mild-flammability considerations where relevant, including notes on equipment compatibility, leak mitigation, and handling procedures. Labs involving refrigerant handling should be performed by—or under the direct supervision of—an instructor holding EPA 608 certification.

Equipment Categories

The following equipment categories are referenced throughout this toolkit. Programs should map these to their available training systems and field equipment.

CATEGORY	DESCRIPTION	LABS
Residential Heat Pump Training System (Ducted/Forced-Air)	Operational ducted heat pump with service ports, thermostat, and service disconnect. Fault insertion capability optional.	3, 10, 11, 12, 14
Residential Mini-Split Heat Pump Training Kit	Operational ductless mini-split with indoor and outdoor units and remote controller. Fault insertion capability optional.	15–20
Refrigerant Recovery and Charging Training System	Recovery machine, gauge manifold, vacuum pump, micron gauge, recovery tank, scale, and associated tools.	4, 7, 8, 9, 17
Refrigeration Circuit Installation Training System	Modular circuit with labeled connection points, metering devices, reversing valve, and electrical cabinet for control wiring.	2, 5

CATEGORY	DESCRIPTION	LABS
Wiring Training Board (Custom Build Option)	Plywood or sheet metal board with mounted electrical components: transformer, contactor, relay, thermostat, pressure switches. Light bulbs/computer fans substitute for HVAC loads.	5, 6, 10
Fault Insertion Software/System	Software or hardware to introduce faults for diagnostic practice. Alternatively, instructors can introduce physical faults manually.	14, 20

Lab Designation Key

DESIGNATION	DESCRIPTION
40-Hour Pathway	Foundational hands-on labs in the standard 40-hour benchmark. Students perform these skills directly.
Instructor-Led Demonstration	Within the 40-hour pathway, delivered as instructor-led demonstrations with student observation and assistance.
Extended Practice	Additional hands-on opportunities for programs beyond 40 hours, incumbent worker upskilling, or programs with diagnostic practice equipment. Extended practice labs may include randomized troubleshooting assessments to build and evaluate learner diagnostic skills.
A2L Consideration	Indicates labs where A2L refrigerant awareness is integrated. These labs include notes on mild-flammability handling, equipment compatibility, and leak mitigation relevant to next-generation refrigerants (e.g., R-454B).

Prerequisites

Students should have EPA 608 certification (or work under direct supervision of a certified instructor) and understand basic circuit theory and multimeter operation prior to beginning this curriculum. All labs involving refrigerant recovery, charging, or system service must be performed by or supervised by an instructor holding EPA 608 certification. This is especially important as the industry transitions to A2L refrigerants, which require additional awareness of mild-flammability safety protocols.

LAB 1

Refrigerant Fundamentals

25–35 min | Proficiency | 40-Hour Pathway

REFRESHER LAB: This lab is a refresher before students progress to hands-on labs.

📋 Required Materials

- Pen and paper
- Traditional Heat Pump (does not need to be running; one unit is sufficient for the entire class)

🦺 Required PPE

Safety glasses should be worn if the equipment is in a shop setting with other students working.

🔧 Instructor Notes

Use this lab as a warm-up to assess student baseline knowledge before proceeding to hands-on labs.
If students struggle with pressure-temperature relationships, spend additional time here before moving to Lab 2.

❄️ Cold Climate Consideration

Discuss how Massachusetts cold climate conditions affect refrigerant behavior: lower ambient temperatures mean lower suction pressures and reduced system capacity.
Introduce the concept of cold climate heat pumps rated for operation below 5°F, which is relevant to the Massachusetts market.

⚠️ A2L Refrigerant Awareness

Under the federal AIM Act, all new residential and light commercial HVAC systems now require A2L refrigerants such as R-454B. Introduce students to the A2L classification (mildly flammable, lower toxicity) and discuss how this affects handling, storage, and equipment selection. Since technicians will encounter A2L systems on virtually every new installation, this foundational context is essential for all labs that follow.

LAB 2

Introduction to HVACR Refrigeration Circuit Installation

LAB 2.1

Interpret HVACR Refrigerant Circuit Diagrams

25–35 min | Proficiency | 40-Hour Pathway

Learning Objectives

Upon completion, the student will be able to:

1. Identify the key components on an HVACR refrigerant circuit diagram
2. Trace refrigerant flow through AC and heat pump circuit configurations
3. Explain the role of each component in the refrigeration cycle
4. Distinguish between directional and unidirectional metering devices

Required Components/Systems

Refrigeration system or training equipment with accessible: compressor, condenser coil, evaporator coil, metering device(s) (capillary tube, TXV, AEV), filter drier, sight glass, reversing valve, suction accumulator, high-side and low-side pressure access ports.

Required Materials

- Refrigerant circuit diagrams for AC and heat pump configurations
- Component symbol reference chart
- Connection point mapping worksheet
- Labeled photo or diagram of available equipment

Required PPE

Safety glasses, gloves, non-melting and non-flammable fabrics, and work boots. Electrical meters available to confirm power is off when required. Main power switch enclosure locked when not in use.

📖 Lesson Procedure

📝 Background

This lab develops the foundational skill of reading refrigerant circuit diagrams—essential for understanding system design, planning service procedures, and troubleshooting. Students work with diagrams for both AC and heat pump systems, learning to recognize differences in refrigerant flow paths and component requirements.

🛠️ Setup

- Distribute circuit diagrams and symbol reference charts to each student or pair
- Position students with clear view of training equipment
- Verify all components are labeled or identifiable

📋 Procedure

1. Review the component symbol reference chart. Discuss each symbol and its corresponding real-world component.
2. Guide students through the AC system diagram, tracing refrigerant flow from compressor through the entire circuit.
3. Transition to the heat pump diagram. Highlight the reversing valve and how it changes refrigerant flow direction between heating and cooling modes.
4. Have students identify all connection points for copper tubing on the training system, matching them to the circuit diagram.
5. Students complete the connection point mapping worksheet.
6. Walk students to training equipment to locate each component identified on the diagrams.

🏁 Closure

- Review completed worksheets as a class
- Discuss directional vs. unidirectional metering devices
- Confirm students can trace refrigerant flow and identify the role of each component

✅ Assessment

- Accuracy of connection point mapping worksheet
- Ability to trace refrigerant flow on AC and heat pump diagrams
- Correct identification of components on equipment
- Verbal explanation of metering device types

💡 Key Teaching Points

- Refrigerant absorbs heat at the evaporator (low-pressure side) and releases heat at the condenser (high-pressure side)
- The compressor increases pressure and temperature; the metering device drops pressure and temperature
- In cooling mode: indoor coil = evaporator, outdoor coil = condenser
- In heating mode (heat pump): the reversing valve swaps the function of indoor and outdoor coils
- Symbols may vary slightly between manufacturers—always reference the specific equipment documentation

> 🔧 **Instructor Notes**
>
> Do this lab as a class for efficiency. It provides a good gauge of student knowledge levels before proceeding to hands-on work.
> A PDF version without answers should be prepared for students to complete independently.

🔄 Equipment Flexibility

- Commercial trainers: Use provided equipment documentation; labeling typically matches manufacturer materials.
- Field equipment: Use installation/service manual documentation; create supplemental labels as needed.
- Component kits: Arrange on bench to simulate system configuration; use generic diagrams.

LAB 3

Introduction to Residential Heat Pump Systems

LAB 3.1

Identify the Components of a Forced-Air Residential Heat Pump System

25–35 min | Proficiency | 40-Hour Pathway

🎯 Learning Objectives

Upon completion, the student will be able to:

1. Identify all major components of a ducted/forced-air heat pump system
2. Describe the physical layout of indoor and outdoor units
3. Explain the role of each component in the refrigeration cycle
4. Locate and identify electrical components: service disconnect, circuit breaker, contactor, and thermostat

⚙️ Required Components/Systems

Ducted/forced-air residential heat pump training system with accessible indoor unit, outdoor unit, compressor, condenser coil, evaporator coil, reversing valve, expansion device, service disconnect, circuit breaker, and diagnostic panel.

📋 Required Materials

- System component identification worksheet
- Equipment layout diagram or labeled photo
- Basic hand tools (10-in-1 screwdriver recommended)
- Magnetic/nonmagnetic hardware bin
- Electrical multimeter
- Lockout/tagout (LOTO) kit

🦺 Required PPE

Safety glasses, gloves, non-melting and non-flammable fabrics, and work boots. Electrical meters available to confirm power is off when required. Main power switch enclosure locked when not in use.

📖 Lesson Procedure

📝 Background

Before students can service or troubleshoot heat pump systems, they must be able to identify all major components and understand the physical layout. This lab establishes component recognition skills using the training system's forced-air heat pump configuration.

🛠️ Setup

- Ensure training system is powered off and locked out
- Distribute identification worksheets and layout diagrams
- Prepare outdoor unit front panel for student access

📋 Procedure

1. Have students locate the training system and identify major sections: indoor unit, outdoor unit, diagnostic panel, and service disconnect.
2. Guide students through removing the outdoor unit front panel for component access. A 10-in-1 screwdriver is ideal for panel screws.
3. Walk students through identification of: compressor, condenser coil, evaporator coil, reversing valve, metering device, accumulator, and filter drier.
4. Have students identify refrigerant piping connections between indoor and outdoor units.
5. Students locate and identify electrical components: service disconnect, circuit breaker, contactor, and thermostat.
6. Students complete the component identification worksheet by matching components to their locations on the training system.

🏁 Closure

- Review completed identification worksheets
- Have students replace outdoor unit front panel
- Discuss the role of each component in the refrigeration cycle

✅ Assessment

- Correct identification of all major components on the training system
- Completed component identification worksheet
- Verbal description of at least three component functions

💡 Key Teaching Points

- The compressor circulates refrigerant by creating a pressure difference
- The reversing valve is unique to heat pumps—it allows the system to switch between heating and cooling
- Service disconnects and lockout/tagout are critical safety features
- Diagnostic panels provide test points for electrical troubleshooting without disassembling the unit

🔧 Instructor Notes

A "pull-out" disconnect is recommended so students can follow the lab steps directly. If using a different style, the instructor should explain how it operates.
The instructor should properly label all components: disconnect, filter drier, thermostat, indoor unit, outdoor unit.
The instructor can use fill-in-the-blank exercises or take photos of the actual equipment with labeled boxes for students to identify.
If the unit does not have electric heat strips, the instructor should still explain their purpose and location.
Most programmable thermostats will work. Having touchscreen and non-touchscreen options for comparison is recommended.

❄️ Cold Climate Consideration

Point out the accumulator and its importance in cold climate operation where liquid floodback risk increases.
If the system has auxiliary/emergency heat strips, discuss when they activate in Massachusetts winter conditions.
Identify defrost components and discuss why defrost cycles are critical in cold, humid Massachusetts winters.

Equipment Flexibility

- Commercial trainers: Use provided equipment documentation; labeling typically matches manufacturer materials.
- Field equipment: Use installation/service manual documentation; create supplemental labels as needed.
- Component kits: Arrange on bench to simulate system configuration; use generic diagrams.

LAB 3.2

Start Up and Shut Down a Forced-Air Residential Heat Pump System

25–35 min | Proficiency | 40-Hour Pathway

Learning Objectives

Upon completion, the student will be able to:

1. Execute proper startup sequence for a residential heat pump
2. Execute proper shutdown sequence
3. Apply lockout/tagout devices correctly
4. Verify system operation after startup

Required Components/Systems

Ducted/forced-air residential heat pump training system with service disconnect, main power disconnect, circuit breaker, and thermostat.

Required Materials

- Startup/shutdown procedure checklist
- Lockout/tagout (LOTO) devices
- Basic hand tools (10-in-1 screwdriver)

Required PPE

Safety glasses, gloves, non-melting and non-flammable fabrics, and work boots. Electrical meters available to confirm power is off when required. Main power switch enclosure locked when not in use.

📖 Lesson Procedure

📝 Background

Safe and correct startup/shutdown procedures protect both the technician and the equipment.

This lab teaches the proper sequence for energizing and de-energizing a heat pump system and introduces lockout/tagout (LOTO) procedures essential for safe servicing.

🛠️ Setup

- Verify system is de-energized and locked out
- Distribute startup/shutdown checklists
- Review LOTO procedures with students before beginning

📋 Procedure

1. Have students verify all safety precautions are in place before energizing the system.
2. Guide students through the proper power-up sequence: service disconnect → main power → circuit breaker.
3. Allow thermostat to initialize (approximately two minutes for electronic thermostats).
4. Set thermostat to cooling mode and adjust set point to initiate a cooling call. Verify compressor, outdoor fan, and indoor blower operation.
5. Observe system running for several minutes to confirm stable operation.
6. Demonstrate proper shutdown sequence: thermostat off → circuit breaker off → main power off → service disconnect off.
7. Apply lockout/tagout devices and have each student practice the LOTO procedure.

🏁 Closure

- Review startup and shutdown checklists
- Discuss why sequence matters (e.g., preventing compressor damage from short cycling)
- Confirm students can independently perform LOTO

✅ Assessment

- Correct execution of startup sequence
- Correct execution of shutdown sequence
- Proper application of lockout/tagout devices
- Ability to verify system operation after startup

💡 Key Teaching Points

- Always follow manufacturer-recommended startup sequence
- LOTO protects the technician from unexpected energization during service
- Electronic thermostats require initialization time after power-up
- Never short-cycle the compressor—allow adequate time between shutdown and restart

❄️ Cold Climate Consideration

Discuss time-delay relays and crankcase heaters: in cold weather, the compressor sump needs to be warm before startup to prevent liquid slugging.
If starting in heating mode during cold conditions, discuss expected pressure ranges and the impact of low ambient on system performance.

🔄 Equipment Flexibility

- Commercial trainers: Use provided equipment documentation; labeling typically matches manufacturer materials.
- Field equipment: Use installation/service manual documentation; create supplemental labels as needed.
- Component kits: Arrange on bench to simulate system configuration; use generic diagrams.

LAB 4

Leak Detection

LAB 4.1

Use Soap Bubble Solution to Check for Refrigerant System Leaks

20–30 min | Proficiency | 40-Hour Pathway | A2L Consideration

Learning Objectives

Upon completion, the student will be able to:

1. Apply soap bubble solution to joints, fittings, and service ports
2. Use a modified Schrader valve cap to check for valve core leaks
3. Document leak detection findings accurately
4. Explain the relationship between soap bubble and electronic leak detection methods

Required Components/Systems

Refrigeration system or heat pump training system with pressurized refrigerant and accessible service ports, joints, and fittings. An empty system can be used if pressurized with nitrogen.

Required Materials

- Modified Schrader valve cap with small hole drilled in center
- Soapy leak detector solution (e.g., Big Blu or equivalent)
- Inspection mirror (for seeing behind pipes and joints)
- Gauge manifold set
- Nitrogen tank and regulator (if system is empty)
- Cotton rags (for wiping off solution)
- Leak detection results recording sheet
- Basic hand tools (screwdrivers, wrenches for panel removal)

Required PPE

Safety glasses, gloves, non-melting and non-flammable fabrics, and work boots. Electrical meters available to confirm power is off when required. Main power switch enclosure locked when not in use.

📖 Lesson Procedure

📝 Background

Leak detection is a critical maintenance and repair skill. While electronic leak detectors identify the general area of a leak, the soap bubble method pinpoints the exact location. This lab teaches the soap bubble technique—one of the most common and reliable methods used in the field.

🛠️ Setup

- If system is empty, pressurize with nitrogen to test pressure (do not exceed equipment MAWP—typically 300–500 psig for residential systems; check the nameplate)
- Remove panels as needed to access components
- Distribute leak detection supplies and recording sheets

📋 Procedure

1. Discuss when the soap bubble method is used (after electronic detection identifies a general area, or for routine maintenance at joints and fittings).
2. Demonstrate use of the modified Schrader valve cap to check service port valve cores for leaks.
3. Have students apply soapy solution to all accessible joints, fittings, and connection points, observing for bubble formation.
4. Guide students in checking both high-side and low-side connections.
5. Students use the inspection mirror to check connections behind pipes and in hard-to-see locations.
6. Have students document each location checked and any leaks found on the recording sheet.
7. Clean all residual soapy solution from components when finished.

🏁 Closure

- Review completed leak detection recording sheets
- Discuss how the soap method complements electronic leak detection
- Explain that empty systems require nitrogen pressurization before using this method

✅ Assessment

- Correct application of soapy solution to joints and fittings
- Proper use of modified Schrader valve cap
- Thoroughness of inspection (all accessible points checked)
- Accurate documentation of results

💡 Key Teaching Points

- Electronic leak detectors identify the general area; soap bubbles pinpoint the exact location
- Always check Schrader valve cores—they are a common leak source
- A system that is empty must be pressurized with nitrogen before leak testing
- Clean all soapy solution from components after testing to prevent corrosion

🔧 Instructor Notes

An empty system is recommended for this lab to avoid unnecessary refrigerant venting.
This lab can also be performed on a mini-split system. If doing so, go over the differences in checking both system types and where components are located.
Use the labeled equipment photos as examples; instructors may want to create site-specific reference photos.

❄️ Cold Climate Consideration

In cold weather, leak detection solution may not bubble as readily. Discuss using electronic detectors first in cold ambient conditions.
Thermal cycling from Massachusetts temperature swings can loosen flare connections over time—emphasize checking these points carefully.

⚠️ A2L Refrigerant Awareness

With all new systems now shipping with A2L refrigerants, leak detection takes on added importance due to mild flammability. Discuss the role of refrigerant leak detectors rated for A2L use and the importance of adequate ventilation during leak testing. Note that some jurisdictions may require fixed leak detection sensors in equipment rooms housing A2L systems. Students should treat A2L leak procedures as the new standard, not the exception.

🔄 Equipment Flexibility

- Commercial trainers: Use provided equipment documentation; labeling typically matches manufacturer materials.
- Field equipment: Use installation/service manual documentation; create supplemental labels as needed.
- Component kits: Arrange on bench to simulate system configuration; use generic diagrams.

LAB 5

Heat Pump System Wiring

40-Hour Pathway

Instructor Notes

If custom wiring training boards are built for this lab (see Equipment Categories), most of Labs 5.1–5.5 and Lab 6 labs can be performed on these boards.
Light bulbs and lamp holders can substitute for HVAC loads (reversing valve, fan, blower, compressor).
Computer fans can be mounted as fan/blower stand-ins. Different colored bulbs can represent different thermostat wires used in industry.
The instructor should create a new line/wire diagram based on the layout of the board that is built.

LAB 5.1

Wire a Control Transformer

30–40 min | Proficiency | 40-Hour Pathway

Learning Objectives

Upon completion, the student will be able to:

1. Identify transformer primary and secondary terminals
2. Wire the primary (line voltage) side to the power source
3. Wire the secondary (control voltage) side to control circuit terminal blocks
4. Verify 24 VAC output using a multimeter

Required Components/Systems

Refrigeration circuit installation training system or custom wiring board with electrical cabinet containing transformer, terminal blocks, and line voltage connections.

📋 Required Materials

- Wire stripper/crimpers and needle nose pliers
- Insulated screwdriver set (6 piece: 3 slotted, 3 Phillips)
- 14 AWG wire (black, white, green)
- Wire nuts and lever wire nuts
- Zip ties and zip tie anchors
- Spiral wire sleeve and stick-on wire labels
- Heat pump circuit diagram (handout)
- Electrical multimeter
- 120V power supply cord
- 120V to 24V transformer

🦺 Required PPE

Safety glasses, gloves, non-melting and non-flammable fabrics, and work boots. Electrical meters available to confirm power is off when required. Main power switch enclosure locked when not in use.

📖 Lesson Procedure

📝 Background

Most HVAC control systems operate on 24 VAC provided by a step-down transformer. This lab teaches students to wire the primary (line voltage) and secondary (control voltage) sides of a control transformer—the first step in building a complete heat pump control circuit.

🛠️ Setup

- Verify system is de-energized and unplugged
- Distribute circuit diagrams showing complete heat pump wiring
- Position students at electrical cabinet with transformer accessible

Procedure

1. Review the complete heat pump circuit diagram, identifying the transformer's role in stepping down line voltage to 24 VAC.
2. Have students locate the transformer and identify primary (line side) and secondary (control side) terminals.
3. Guide students in connecting the primary winding to the line voltage source using proper wire gauge and connections.
4. Have students connect the secondary winding to the control circuit terminal blocks.
5. After instructor verification of wiring, energize the system and verify 24 VAC output at the secondary terminals using a multimeter.

Closure

- Verify all students measured correct transformer output voltage
- Discuss why control voltage (24 VAC) is used instead of line voltage for safety
- Preview how the thermostat connects in Lab 5.2

Assessment

- Correct wiring of primary and secondary connections
- Measured 24 VAC (±10%) at secondary terminals
- Proper use of wire connectors and neat routing

Key Teaching Points

- The transformer steps down 120 VAC or 240 VAC to 24 VAC for safety
- The primary side connects to line voltage; the secondary side provides control voltage
- Always verify the system is de-energized before making wiring connections

Equipment Flexibility

- Commercial trainers: Use provided equipment documentation; labeling typically matches manufacturer materials.
- Field equipment: Use installation/service manual documentation; create supplemental labels as needed.
- Component kits: Arrange on bench to simulate system configuration; use generic diagrams.

LAB 5.2

Wire an Electronic Heat Pump Thermostat

30–40 min | Proficiency | 40-Hour Pathway

🎯 Learning Objectives

Upon completion, the student will be able to:

1. Identify thermostat terminal designations (R, C, Y, G, O/B, W, E)
2. Wire a heat pump thermostat using proper color codes
3. Verify thermostat operation by initiating heating and cooling calls

📋 Required Materials

- 18 AWG thermostat wire (orange, blue, red, and additional colors)
- Thermostat (touchscreen and non-touchscreen options recommended)
- Thermostat wire
- Insulated screwdriver set
- Electrical multimeter
- Terminal identification chart

🦺 Required PPE

Safety glasses, gloves, non-melting and non-flammable fabrics, and work boots. Electrical meters available to confirm power is off when required. Main power switch enclosure locked when not in use.

📖 Lesson Procedure

📝 Background

The thermostat is the user interface that controls heating, cooling, and fan operation. Heat pump thermostats include additional terminals (O/B for reversing valve, E for emergency heat) not found on standard AC thermostats. This lab teaches proper heat pump thermostat wiring.

📋 Procedure

1. Review terminal designations: R (24 VAC hot), C (common), Y (compressor), G (fan), O/B (reversing valve), W (aux heat), E (emergency heat).
2. Guide students in running thermostat cable from the control panel to the thermostat location.
3. Have students connect thermostat wires to the corresponding terminals at both the control panel and thermostat ends.
4. After instructor verification, energize and test: initiate cooling call (Y + G + O active), heating call (Y + G + O de-energized), fan-only (G only).
5. Verify correct voltage at each terminal during each operating mode.

✅ Assessment

- Correct wiring at thermostat and control panel terminals
- System responds correctly to heating, cooling, and fan-only calls
- Student can explain O/B terminal function for reversing valve

💡 Key Teaching Points

- Heat pump thermostats have an O/B terminal for the reversing valve that standard AC stats lack
- R provides 24 VAC from the transformer; C is the common return
- Color codes may vary—always reference the specific thermostat and equipment documentation
- Emergency heat (E terminal) bypasses the heat pump and runs auxiliary strips only

❄️ Cold Climate Consideration

Discuss the O vs. B terminal difference: O energizes the reversing valve in cooling (most common), B energizes in heating. This varies by manufacturer and is critical in cold climates where heating is the primary mode.

Emphasize the emergency heat function—in a Massachusetts cold snap, homeowners may need to use emergency heat if the heat pump malfunctions or cannot provide sufficient heat.

🔄 Equipment Flexibility

- Commercial trainers: Use provided equipment documentation; labeling typically matches manufacturer materials.
- Field equipment: Use installation/service manual documentation; create supplemental labels as needed.
- Component kits: Arrange on bench to simulate system configuration; use generic diagrams.

LAB 5.3

Wire a Motor Contactor

25–35 min | Proficiency | 40-Hour Pathway

🎯 Learning Objectives

Upon completion, the student will be able to:

1. Wire a 24V contactor coil to the control circuit
2. Wire line voltage through the contactor to a simulated compressor load
3. Verify contactor operation (pull-in and drop-out) using a multimeter

📋 Required Materials

- 24V 2-pole contactor
- 120V light bulb/lamp holder (simulated compressor load)
- 120V computer fan (optional alternate load)
- Insulated screwdriver set, wire, multimeter

📖 Lesson Procedure

Students wire the contactor coil to the 24 VAC control circuit (Y terminal from thermostat) and route line voltage through the contactor's load contacts to a simulated compressor (light bulb or computer fan). When the thermostat calls for cooling, the contactor energizes and the load activates. Students verify coil voltage, contact closure, and load operation.

💡 Key Teaching Points

- The contactor is the "heavy-duty switch" that allows low-voltage control signals to switch high-voltage loads
- Always check contactor contacts for pitting or burning during service—a common failure point
- The coil side is 24 VAC from the control circuit; the load side carries line voltage

Equipment Flexibility

- Commercial trainers: Use provided equipment documentation; labeling typically matches manufacturer materials.
- Field equipment: Use installation/service manual documentation; create supplemental labels as needed.
- Component kits: Arrange on bench to simulate system configuration; use generic diagrams.

LAB 5.4

Wire a Reversing Valve

25–35 min | Proficiency | 40-Hour Pathway

Learning Objectives

Upon completion, the student will be able to:

1. Wire a reversing valve solenoid to the O/B terminal circuit
2. Verify reversing valve energizes/de-energizes correctly in heating and cooling modes
3. Explain O-type vs. B-type wiring differences

Lesson Procedure

Students connect the reversing valve solenoid coil to the thermostat's O/B terminal through the control circuit. They then verify operation by switching between heating and cooling modes, confirming the solenoid energizes (or de-energizes, depending on O vs. B configuration) at the correct time. Multimeter readings confirm 24 VAC at the solenoid during the appropriate mode.

Key Teaching Points

- The reversing valve changes refrigerant flow direction between heating and cooling
- O-type: energized in cooling. B-type: energized in heating.
- A stuck reversing valve is a common field failure that can lock the system in one mode

❄️ **Cold Climate Consideration**

In Massachusetts, heating mode is the dominant operating mode. Emphasize that a failed reversing valve in a B-type system could leave the home without heat.
Discuss the pilot-operated design: the solenoid shifts a pilot valve that redirects high-pressure refrigerant to move the main valve slide.

Equipment Flexibility

- Commercial trainers: Use provided equipment documentation; labeling typically matches manufacturer materials.
- Field equipment: Use installation/service manual documentation; create supplemental labels as needed.
- Component kits: Arrange on bench to simulate system configuration; use generic diagrams.

LAB 5.5

Verify the Wiring of a Heat Pump System

30–40 min | Proficiency | 40-Hour Pathway

Learning Objectives

Upon completion, the student will be able to:

1. Systematically verify all wiring connections in a complete heat pump control circuit
2. Use a multimeter to confirm correct voltages at each component
3. Identify and correct wiring errors

Lesson Procedure

This capstone wiring lab has students verify the complete control circuit built in Labs 5.1–5.4.

Students systematically check transformer output, thermostat terminal voltages, contactor coil/load circuits, reversing valve solenoid, and fan relay operation. They document voltage readings at each test point and identify any discrepancies. The instructor may intentionally introduce a wiring error for students to find.

💡 Key Teaching Points

- A systematic approach to wiring verification prevents callbacks and equipment damage
- Always start at the power source and work outward through the circuit
- Compare measured voltages to expected values at each point
- Document all readings—this is the same process used for warranty service calls

🔄 Equipment Flexibility

- Commercial trainers: Use provided equipment documentation; labeling typically matches manufacturer materials.
- Field equipment: Use installation/service manual documentation; create supplemental labels as needed.
- Component kits: Arrange on bench to simulate system configuration; use generic diagrams.

LAB 6

Heat Pump Control Circuits

eLEARNING + SUPPLEMENTAL HANDS-ON: This lab extends control circuit concepts from Lab 5. If wiring boards were built for Lab 5, most of this lab can be performed on those boards.

Additional Equipment for This Lab (beyond Lab 5 boards)

- High, low, and fan cycle pressure switches
- Air compressor or nitrogen tank with regulator and fittings (to actuate pressure switches)
- Reversing valve (physical component for bench mounting)
- Float switch (condensate safety)
- Service disconnect (a single pole light switch can substitute)

🔧 **Instructor Notes**

This lab can also be performed on an existing traditional ducted heat pump if wiring boards are not available.
The instructor should create a line/wire diagram based on the specific board layout built for the program.
Use pressure switches with an air compressor or nitrogen to demonstrate cut-in and cut-out pressures—this is an excellent visual for students.

💡 Key Teaching Points

- Pressure switches protect the system from operating outside safe ranges
- The high-pressure cutout prevents compressor damage from excessive head pressure
- The low-pressure cutout prevents damage from loss of charge or blocked airflow
- Float switches prevent water damage from clogged condensate drains

❄️ **Cold Climate Consideration**

In cold climates, the low-pressure cutout setting is critical: low ambient temperatures can drive suction pressure below the cutout point, causing nuisance trips.
Discuss how cold climate heat pumps are designed with wider operating pressure envelopes than conventional systems.
The defrost control circuit is an important addition in cold climate applications—discuss how it integrates with the overall control scheme.

LAB 7

Refrigerant Recovery Preparation

LAB 7.1

Remove a Schrader Valve Core from a Service Port

20–30 min | Proficiency | 40-Hour Pathway

🎯 Learning Objectives

Upon completion, the student will be able to:

1. Safely remove a Schrader valve core from a service port using the proper tool
2. Reinstall a Schrader valve core and verify it is seated correctly
3. Explain why Schrader core removal improves recovery speed and vacuum depth

📋 Required Materials

- 2 Schrader core removal tools
- Gauge manifold set with hoses
- 2 extra ¼" refrigerant hoses
- Schrader cores (replacement)
- Clean rags

🦺 Required PPE

Safety glasses, gloves, non-melting and non-flammable fabrics, and work boots. Electrical meters available to confirm power is off when required. Main power switch enclosure locked when not in use.

📖 Lesson Procedure

📝 Background

Schrader valve cores in service ports restrict refrigerant flow during recovery and prevent deep vacuum during evacuation. Removing the cores before connecting recovery equipment dramatically improves recovery speed and vacuum depth. This is a fundamental field skill.

📋 Procedure

1. Demonstrate the Schrader core removal tool and explain its operation.
2. Have students practice core removal and reinstallation on a de-pressurized system first.
3. Once comfortable, have students practice with refrigerant pressure or nitrogen in the system (instructor supervised).
4. Verify cores are properly reseated by checking for leaks with soap bubble solution.

> **🔧 Instructor Notes**
>
> Have students practice removing and installing Schrader cores with refrigerant pressure or nitrogen in the system—this builds confidence for field work where you often cannot fully depressurize first. Emphasize speed and dexterity—in the field, minimizing refrigerant loss during core removal is important.

💡 Key Teaching Points

- Schrader cores are a common source of minor leaks—always check after servicing
- Removing cores before recovery and evacuation significantly reduces service time
- Always use the correct tool—pliers or improvised tools can damage the core and port threads

🔄 Equipment Flexibility

- Commercial trainers: Use provided equipment documentation; labeling typically matches manufacturer materials.
- Field equipment: Use installation/service manual documentation; create supplemental labels as needed.
- Component kits: Arrange on bench to simulate system configuration; use generic diagrams.

LAB 7.2

Prepare a Recovery Tank to Store Refrigerant

20–30 min | Proficiency | 40-Hour Pathway | A2L Consideration

🎯 Learning Objectives

Upon completion, the student will be able to:

1. Inspect a recovery tank for proper certification and condition
2. Verify tank is evacuated and ready for use
3. Connect recovery tank to recovery equipment correctly
4. Explain the 80% fill rule and weight tracking requirements

📋 Required Materials

- Empty recovery tank (DOT-rated)
- Scale (accurate to ±0.25 oz)
- Vacuum pump
- Micron gauge
- Gauge manifold set

📖 Lesson Procedure

Students inspect the recovery tank for certification date, condition, and proper labeling. They evacuate the tank using the vacuum pump, verify vacuum depth with the micron gauge, and record the tare weight. Students learn to calculate the 80% fill limit based on tank capacity and the importance of accurate weight tracking for EPA compliance.

💡 Key Teaching Points

- Recovery tanks must not exceed 80% liquid capacity—this prevents dangerous overpressure
- Always record tare weight before recovery begins
- DOT certification must be current; expired tanks cannot be used for transport
- EPA requires accurate weight documentation for all recovered refrigerant

🔄 Equipment Flexibility

- Commercial trainers: Use provided equipment documentation; labeling typically matches manufacturer materials.
- Field equipment: Use installation/service manual documentation; create supplemental labels as needed.
- Component kits: Arrange on bench to simulate system configuration; use generic diagrams.

⚠️ A2L Refrigerant Awareness

When working with A2L refrigerants (R-454B), verify that recovery tanks and equipment are rated for A2L use. Standard R-410A tanks may not carry the appropriate certification for mildly flammable refrigerants.

LAB 8

Refrigerant Recovery and Recycling

LAB 8.1

Recover Refrigerant from a System

35–45 min | Proficiency | 40-Hour Pathway | A2L Consideration

Learning Objectives

Upon completion, the student will be able to:

1. Connect recovery equipment to a heat pump system
2. Operate a recovery machine to EPA-compliant termination pressure
3. Verify recovery is complete using the required standing pressure test
4. Document refrigerant type and weight recovered

Required Materials

- Running or charged residential ducted split heat pump unit
- Lockout/tagout kit
- 3 Schrader core removal tools
- Gauge manifold set and 2 extra ¼" hoses
- 2 vacuum-rated refrigerant hoses
- Recovery machine
- Empty recovery tank and scale
- ¼" flare filter drier
- Wrench set or 2 adjustable wrenches
- Allen wrench set
- Clean rags, leak detection solution
- Extension cord

Required PPE

Safety glasses, gloves, non-melting and non-flammable fabrics, and work boots. Electrical meters available to confirm power is off when required. Main power switch enclosure locked when not in use.

📖 Lesson Procedure

📝 Background

Proper refrigerant recovery is legally required before opening any system for service or disposal. This lab teaches the complete recovery process using industry-standard equipment and EPA-compliant procedures.

📋 Procedure

1. Remove Schrader valve cores from service ports to maximize flow.
2. Install inline filter drier to protect recovery machine from contaminants.
3. Connect gauge manifold to system and recovery machine to recovery tank (on scale).
4. Open valves, purge air, and start recovery machine. Monitor pressures and tank weight.
5. Continue recovery until the system reaches 0 psig (EPA requirement for high-pressure systems under 200 lbs).
6. Perform standing pressure test: close valves, wait, and verify pressure does not rise above threshold.
7. Document: refrigerant type, amount recovered, tank ID, date.

✅ Assessment

- Correct equipment setup and connections
- Recovery to EPA-compliant termination pressure (0 psig for high-pressure systems <200 lbs)
- Accurate weight documentation
- Proper standing pressure test execution

💡 Key Teaching Points

- EPA 608 requires recovery to 0 psig for high-pressure systems under 200 lbs—not 5 psig
- Always use an inline filter drier to protect the recovery machine
- Remove Schrader cores before recovery to significantly reduce time
- The standing pressure test verifies that all recoverable refrigerant has been removed

🔧 Instructor Notes

Have students practice removing and installing Schrader cores with pressure in the system during this lab as well.
The instructor should properly label all components before student access: disconnect, filter drier, indoor unit, outdoor unit, etc.
If using A2L refrigerant, ensure recovery machine is rated for A2L use.

❄️ Cold Climate Consideration

In cold ambient conditions, refrigerant migrates to the coldest part of the system. Discuss applying gentle heat to the outdoor unit to improve recovery rates in cold weather.

Low ambient temperatures slow recovery—students should understand this will take longer on a cold Massachusetts day.

⚠️ A2L Refrigerant Awareness

Since all new systems require A2L refrigerants, technicians must be prepared to recover mildly flammable refrigerants as standard practice. Ensure the recovery machine is rated for A2L use—equipment designed exclusively for R-410A may not carry the appropriate certification. Maintain adequate ventilation, avoid ignition sources, and perform this lab under direct supervision of an EPA 608–certified instructor.

🔄 Equipment Flexibility

- Commercial trainers: Use provided equipment documentation; labeling typically matches manufacturer materials.
- Field equipment: Use installation/service manual documentation; create supplemental labels as needed.
- Component kits: Arrange on bench to simulate system configuration; use generic diagrams.

LAB 8.2

Use a Micron Gauge to Check System Evacuation Level

25–35 min | Proficiency | 40-Hour Pathway

🎯 Learning Objectives

Upon completion, the student will be able to:

1. Connect and calibrate a micron gauge
2. Perform a system evacuation to the specified micron level
3. Perform a standing vacuum test to verify system integrity
4. Interpret micron gauge readings and identify evacuation problems

📖 Lesson Procedure

Students connect the micron gauge directly to the system (not through the gauge manifold, which introduces restriction). They evacuate the system using the vacuum pump and monitor the micron gauge until reaching the target level (typically 500 microns). A standing vacuum test follows: the pump is isolated and the system is monitored for pressure rise, which indicates a leak or moisture.

💡 Key Teaching Points

- Connect the micron gauge directly to the system—not through the gauge manifold—for accurate readings
- Target 500 microns for proper evacuation; if pressure rises above 1000 microns during standing test, investigate for leaks or moisture
- Moisture in the system is the number one enemy—it causes acid formation and compressor failure
- Vacuum pump oil must be changed regularly for effective deep vacuum

🔄 Equipment Flexibility

- Commercial trainers: Use provided equipment documentation; labeling typically matches manufacturer materials.
- Field equipment: Use installation/service manual documentation; create supplemental labels as needed.
- Component kits: Arrange on bench to simulate system configuration; use generic diagrams.

LAB 8.3

Charge a System with Recovered Refrigerant

30–40 min | Proficiency | 40-Hour Pathway | A2L Consideration

🎯 Learning Objectives

Upon completion, the student will be able to:

1. Set up charging equipment with proper connections and safety
2. Charge a system by weight using a scale
3. Verify proper charge using system performance measurements

📖 Lesson Procedure

After evacuation, students charge the system with recovered refrigerant by weight per the manufacturer's nameplate specification. They monitor pressures during charging, verify the correct weight has been added using the scale, and run the system to confirm proper operation.

If the system uses a blend refrigerant (R-410A or R-454B), students charge in liquid phase only. When charging A2L refrigerants, ensure adequate ventilation and that all equipment is rated for mildly flammable refrigerants.

💡 Key Teaching Points

- Blend refrigerants (R-410A, R-454B) must always be charged as a liquid to prevent fractionation
- A liquid vaporizer on the suction hose prevents liquid slugging the compressor during low-side charging
- Always charge by weight—"just add until it looks right" is not acceptable practice
- Verify charge by measuring superheat and/or subcooling after system stabilizes

❄️ Cold Climate Consideration

In cold ambient conditions, subcooling readings may differ from warm-weather norms.
Refer to manufacturer specifications for cold-weather charging charts.
Some cold climate heat pumps have different charge specifications for heating vs. cooling mode operation.

🔄 Equipment Flexibility

- Commercial trainers: Use provided equipment documentation; labeling typically matches manufacturer materials.
- Field equipment: Use installation/service manual documentation; create supplemental labels as needed.
- Component kits: Arrange on bench to simulate system configuration; use generic diagrams.

⚠️ A2L Refrigerant Awareness

When charging A2L refrigerants, ensure adequate ventilation and that all equipment (scales, recovery machine, hoses) is rated for mildly flammable use. Charge in liquid phase only.

LAB 9

Refrigerant System Charging

LAB 9.1

Use the Weigh-In Method to Charge a System

30–40 min | Proficiency | 40-Hour Pathway

Learning Objectives

Upon completion, the student will be able to:

1. Calculate required charge from manufacturer nameplate data
2. Set up charging equipment and scale
3. Charge virgin refrigerant by weight in liquid phase
4. Verify system operation after charging

Required Materials

- Running residential ducted split heat pump unit
- Lockout/tagout kit and basic hand tools
- Gauge manifold set and scale
- Refrigerant cylinder (R-410A, R-454B, or other as applicable to the training system)
- Liquid vaporizer
- ¼" flare filter drier
- Temperature probe and digital thermometer
- Clean rags

Lesson Procedure

Students read the nameplate charge specification and calculate the total required charge including any line set correction. They set up the scale, connect charging equipment, and add refrigerant in liquid phase to the specified weight. After charging, they run the system and verify operation through pressure and temperature measurements.

🔧 Instructor Notes

If the refrigerant charge is already within spec, the student can intentionally alter the charge for the next student. This way the student still demonstrates proper charging technique AND it saves the instructor from having to adjust the charge between each student rotation.
Have students practice removing and installing Schrader cores with pressure in the system during this lab.

💡 Key Teaching Points

- The nameplate specifies the factory charge; add or subtract for line set length differences from factory spec
- Always charge blends (R-410A, R-454B) in liquid phase
- Use a liquid vaporizer when charging through the suction side to prevent liquid slugging
- Record all charge amounts for the service record
- Verify charge by measuring superheat and/or subcooling after system stabilizes

❄️ Cold Climate Consideration

Discuss the importance of charging in the correct mode: manufacturers may specify charging in cooling mode even if the system will primarily operate in heating.
Cold ambient temperatures during charging can produce misleading pressure readings— discuss manufacturer correction charts.

🔄 Equipment Flexibility

- Commercial trainers: Use provided equipment documentation; labeling typically matches manufacturer materials.
- Field equipment: Use installation/service manual documentation; create supplemental labels as needed.
- Component kits: Arrange on bench to simulate system configuration; use generic diagrams.

LAB 9.2

Use the Subcooling Method to Verify System Charge

30–40 min | Proficiency | 40-Hour Pathway

🎯 Learning Objectives

Upon completion, the student will be able to:

1. Measure liquid line pressure and temperature
2. Calculate subcooling from measured values
3. Compare measured subcooling to manufacturer specification
4. Determine if the system is properly charged, undercharged, or overcharged

📖 Lesson Procedure

With the system running in cooling mode, students connect the gauge manifold to the liquid

(high-side) service port and attach a temperature clamp to the liquid line. They record the condensing temperature (from the high-side pressure and P-T chart) and the actual liquid line temperature. Subcooling = condensing temperature – liquid line temperature. Results are compared to the manufacturer's specification.

💡 Key Teaching Points

- Subcooling within specification = properly charged
- Low subcooling = undercharged (not enough liquid in condenser)
- High subcooling = overcharged or restriction downstream of measurement point
- Always disconnect gauge manifold hoses properly to minimize refrigerant loss—close manifold valves first

> **❄️ Cold Climate Consideration**
>
> Subcooling is the preferred charge verification method for systems with TXVs or EEVs, which are common in cold climate heat pumps.
> In heating mode, the "liquid line" becomes the line between the indoor metering device and the outdoor coil—students need to understand this reversal.

🔄 Equipment Flexibility

- Commercial trainers: Use provided equipment documentation; labeling typically matches manufacturer materials.
- Field equipment: Use installation/service manual documentation; create supplemental labels as needed.
- Component kits: Arrange on bench to simulate system configuration; use generic diagrams.

LAB 10

Heat Pump Thermostat Operation

LAB 10.1

Adjust Thermostat Settings Using a User Interface

20–30 min | Proficiency | 40-Hour Pathway

🎯 Learning Objectives

Upon completion, the student will be able to:

1. Navigate thermostat menu systems and adjust temperature set points
2. Configure heating/cooling mode, fan settings, and program schedules
3. Identify and explain thermostat indicators and display information

📖 Lesson Procedure

Students work with the installed thermostat to explore all user-accessible settings. They adjust set points, switch between modes (heat, cool, auto, emergency heat), configure fan settings (auto, on), and set up a basic program schedule. Having both touchscreen and non-touchscreen thermostat options available allows students to see the range of interfaces they will encounter in the field.

> 🔧 **Instructor Notes**
>
> If wiring boards from Lab 5 are available, this lab can be done on those boards.
> The instructor should create a line/wire diagram based on the board layout.
> Most programmable thermostats will work for this lab. Having multiple styles available is ideal.

💡 Key Teaching Points

- Heat pump thermostats have unique settings not found on standard AC thermostats: emergency heat, auxiliary heat lockout temperatures, balance point settings
- Educating homeowners on thermostat operation is an important part of a technician's job
- Setback schedules in heating mode should be modest (2–4°F) to avoid excessive auxiliary heat use

❄️ Cold Climate Consideration

In Massachusetts, large thermostat setbacks can trigger expensive auxiliary electric heat during recovery periods. Educate students to advise homeowners to use modest setbacks.
Many modern smart thermostats have heat pump-specific modes that manage auxiliary heat intelligently—demonstrate these if available.

🔄 Equipment Flexibility

- Commercial trainers: Use provided equipment documentation; labeling typically matches manufacturer materials.
- Field equipment: Use installation/service manual documentation; create supplemental labels as needed.
- Component kits: Arrange on bench to simulate system configuration; use generic diagrams.

LAB 10.2

Operate a Heat Pump in Heating and Cooling Modes

25–35 min | Proficiency | 40-Hour Pathway

🎯 Learning Objectives

Upon completion, the student will be able to:

1. Initiate heating and cooling calls from the thermostat
2. Observe and describe system response in each mode
3. Identify which components are active in each operating mode
4. Measure supply and return air temperatures to verify performance

📖 Lesson Procedure

Students operate the heat pump in both modes, observing the startup sequence, component activation, and system sounds. In cooling mode, they verify the outdoor fan, compressor, and indoor blower are running. In heating mode, they confirm the reversing valve shifts and the system produces heat. Temperature measurements at supply and return registers confirm performance.

💡 Key Teaching Points

- In cooling mode: expect 15–22°F temperature drop across the evaporator (supply vs. return)
- In heating mode: expect 15–30°F temperature rise at the supply (varies with outdoor temperature)
- The reversing valve click or hum may be audible during mode change
- Allow 5–10 minutes for system to stabilize before taking performance measurements

> **❄️ Cold Climate Consideration**
>
> Heat pump supply air temperatures in heating mode (typically 90–95°F) feel cooler than furnace output (120–140°F). This is normal but a common homeowner complaint— technicians should be prepared to explain it.
> In very cold conditions, the system may activate auxiliary heat to supplement—observe and discuss this behavior.

🔄 Equipment Flexibility

- Commercial trainers: Use provided equipment documentation; labeling typically matches manufacturer materials.
- Field equipment: Use installation/service manual documentation; create supplemental labels as needed.
- Component kits: Arrange on bench to simulate system configuration; use generic diagrams.

LAB 11

Pressure and Temperature Measurements

⚠️ **A2L Refrigerant Lab**

All new residential and light commercial systems now ship with A2L refrigerants (e.g., R-454B), making A2L proficiency essential for every technician. Several skills in this lab incorporate A2L-specific considerations including gauge manifold preparation for A2L systems, pressure measurement techniques, and subcooling verification on A2L-charged equipment. All refrigerant handling in this lab should be performed by or under the direct supervision of an EPA 608–certified instructor.

LAB 11.1

Prepare the Gauge Manifold for Use

20–30 min | Proficiency | 40-Hour Pathway | A2L Consideration

🎯 Learning Objectives

Upon completion, the student will be able to:

1. Inspect gauge manifold components and hoses
2. Calibrate the gauges and verify calibration
3. Connect hoses to the gauge manifold correctly

📖 Lesson Procedure

Students inspect the gauge manifold for damage, leaks, and proper operation. They calibrate both gauges, check hose connections, and verify all valves are in the closed position. This foundational skill ensures accurate readings in subsequent pressure measurement labs.

💡 Key Teaching Points

- Always calibrate gauges before use—even slight calibration drift can lead to incorrect diagnoses
- Inspect hose gaskets regularly—damaged gaskets cause false low readings and refrigerant leaks
- The low-side (compound) gauge reads both pressure and vacuum
- Keep gauge manifold valves closed unless intentionally transferring refrigerant
- When servicing A2L systems, verify that gauges and hoses are rated for the specific refrigerant—standard R-410A gauge sets may have different pressure ranges than A2L-specific equipment

🔄 Equipment Flexibility

- Commercial trainers: Use provided equipment documentation; labeling typically matches manufacturer materials.
- Field equipment: Use installation/service manual documentation; create supplemental labels as needed.
- Component kits: Arrange on bench to simulate system configuration; use generic diagrams.

LAB 11.2

Use a Gauge Manifold to Measure System Pressures

25–35 min | Proficiency | 40-Hour Pathway | A2L Consideration

🎯 Learning Objectives

Upon completion, the student will be able to:

1. Connect the gauge manifold to high-side and low-side service ports
2. Read and record operating pressures in both heating and cooling modes
3. Convert pressures to saturation temperatures using a P-T chart

📋 Required Materials

- Running residential ducted split heat pump unit
- Gauge manifold set
- Wrench set or adjustable wrenches
- P-T chart for system refrigerant (R-410A and/or R-454B)
- Pressure/temperature recording worksheet

📖 Lesson Procedure

Students connect the gauge manifold to the system's high-side and low-side service ports while the system is running. They record pressures in both cooling and heating modes, convert to saturation temperatures using the P-T chart, and compare to expected operating ranges for the current ambient conditions.

💡 Key Teaching Points

- Low-side pressure corresponds to evaporator saturation temperature; high-side corresponds to condenser saturation temperature
- Expected operating ranges vary with outdoor ambient temperature—always account for conditions
- Unusual pressure readings are the first indicator of system problems
- A2L refrigerants such as R-454B operate at different pressure-temperature relationships than R-410A —always use the correct P-T chart for the refrigerant in the system

> **❄️ Cold Climate Consideration**
>
> In heating mode at low ambient temperatures, expect lower suction pressures and lower discharge pressures than in cooling mode.
> Discuss how cold climate heat pumps maintain capacity: variable-speed compressors increase speed as ambient drops, which raises suction pressure compared to fixed-speed units.

🔄 Equipment Flexibility

- Commercial trainers: Use provided equipment documentation; labeling typically matches manufacturer materials.
- Field equipment: Use installation/service manual documentation; create supplemental labels as needed.
- Component kits: Arrange on bench to simulate system configuration; use generic diagrams.

LAB 11.3

Test for a Restriction or Blockage

30–40 min | Proficiency | 40-Hour Pathway

🎯 Learning Objectives

Upon completion, the student will be able to:

1. Identify pressure and temperature symptoms of a restriction
2. Use temperature measurements across components to locate a restriction
3. Distinguish between a metering device restriction and a liquid line restriction

📖 Lesson Procedure

The instructor can install and adjust instructor-installed ball valves in the liquid and/or suction lines to simulate restrictions.

Students measure pressures and temperatures across suspected restriction points, noting abnormal temperature drops that indicate a blockage. They document symptoms and diagnose the restriction location using a systematic approach.

> 🔧 **Instructor Notes**
>
> Instructor-installed ball valves in the liquid and suction lines allow the instructor to simulate restrictions and blockages without physically altering the system.
> Adjust valve positions before each student rotation to create different scenarios.
> Consider adding PC-based fault insertion as an option for training programs with that capability.

💡 Key Teaching Points

- A restriction causes a measurable temperature drop across the restricted point
- High subcooling with low suction pressure often indicates a liquid line restriction
- A partially blocked filter drier is one of the most common field restrictions
- Frost or sweating on a component can visually indicate a restriction

> ❄️ **Cold Climate Consideration**
>
> In cold weather, moisture freezing at the metering device can cause a restriction. Discuss how proper evacuation prevents this.
> Cold climate systems with EEVs are less susceptible to ice-related restrictions than TXV systems.

🔄 Equipment Flexibility

- Commercial trainers: Use provided equipment documentation; labeling typically matches manufacturer materials.
- Field equipment: Use installation/service manual documentation; create supplemental labels as needed.
- Component kits: Arrange on bench to simulate system configuration; use generic diagrams.

LAB 11.4

Measure Thermal System Temperatures

25–35 min | Proficiency | 40-Hour Pathway

🎯 Learning Objectives

Upon completion, the student will be able to:

1. Use pipe clamp and probe thermometers to measure line temperatures
2. Measure supply air, return air, and outdoor ambient temperatures
3. Calculate temperature differentials and compare to specifications

📖 Lesson Procedure

Students use pipe clamp thermometers on suction and liquid lines, probe thermometers for air temperatures, and record all readings. They calculate the supply-to-return temperature differential and compare to expected values. Proper probe placement and insulation techniques are emphasized for accurate readings.

💡 Key Teaching Points

- Insulate pipe clamp probes from ambient air for accurate readings—use foam or tape
- Temperature readings are more accessible and less invasive than pressure measurements
- A consistent measurement technique is essential for reliable diagnostics

❄️ Cold Climate Consideration

In heating mode, suction line temperature indicates heat absorption from outdoor air. As ambient drops, suction temperature drops—discuss the relationship.
Low outdoor ambient means lower supply air temperatures from the heat pump. Typical heating supply air is 90–95°F vs. 120–140°F for a gas furnace.

Equipment Flexibility

- Commercial trainers: Use provided equipment documentation; labeling typically matches manufacturer materials.
- Field equipment: Use installation/service manual documentation; create supplemental labels as needed.
- Component kits: Arrange on bench to simulate system configuration; use generic diagrams.

LAB 11.5

Determine If a System Is Properly Charged Using Subcooling

25–35 min | Proficiency | 40-Hour Pathway | A2L Consideration

Learning Objectives

Upon completion, the student will be able to:

1. Calculate subcooling from pressure and temperature measurements
2. Compare measured subcooling to manufacturer specification
3. Diagnose overcharge vs. undercharge conditions

Lesson Procedure

Building on skills from Labs 11.2 and 11.4, students measure liquid line pressure (to determine condensing temperature) and liquid line temperature simultaneously. They calculate subcooling and compare to the manufacturer's specification. The instructor may adjust the system charge to let students experience both undercharge (low subcooling) and overcharge (high subcooling) conditions.

💡 Key Teaching Points

- Subcooling within spec = properly charged
- Low subcooling = undercharged (not enough liquid in condenser)
- High subcooling = overcharged or restriction downstream of measurement point
- Always disconnect gauge manifold hoses properly—close manifold valves first to minimize refrigerant loss

❄️ Cold Climate Consideration

Subcooling is the preferred charge verification method for systems with TXVs/EEVs common in cold climate heat pumps.
In heating mode, take subcooling at the outdoor unit where the condenser function has shifted.

⚠️ A2L Refrigerant Awareness

Students must use the correct P-T chart for the refrigerant in the system—R-454B has different saturation properties than R-410A. Subcooling targets may also differ per manufacturer specifications for A2L equipment. Ensure all service performed on charged systems is supervised by an EPA 608–certified instructor.

🔄 Equipment Flexibility

- Commercial trainers: Use provided equipment documentation; labeling typically matches manufacturer materials.
- Field equipment: Use installation/service manual documentation; create supplemental labels as needed.
- Component kits: Arrange on bench to simulate system configuration; use generic diagrams.

LAB 12

Heat Pump Component Tests

40-Hour Pathway | Instructor-Led Demonstration | Extended Practice

This lab covers diagnostic testing procedures for major heat pump components. In a 40-hour pathway, these are delivered as instructor-led demonstrations: the instructor performs the diagnostic while students observe, assist with measurements, and learn the decision-making logic. Programs with extended time can deliver these as full hands-on student rotations.

Each skill focuses on fault scenarios that can be reliably created and reset by an instructor using manual techniques. The diagnostic approach follows a consistent workflow: observe symptoms, consult the troubleshooting table, perform targeted measurements, interpret the results, and document the findings.

Required Components/Systems

Residential ducted heat pump training system (operational) with accessible compressor, contactor, capacitor, reversing valve, defrost control board, blower motor, outdoor fan motor, thermostat wiring, and service disconnect. Ball valves pre-installed in liquid and suction lines for restriction simulation. Fault insertion capability optional—all scenarios can be created manually.

Required Diagnostic Tools

- Digital multimeter (AC voltage, DC voltage, resistance, capacitance)
- Clamp-on ammeter
- Gauge manifold with hoses and low-loss ball valve adapters
- Pipe-clamp temperature probe and digital thermometer
- Pocket thermometer
- Jumper wire with insulated clips (for thermostat bypass tests)
- 20,000 Ω resistor (for capacitor discharge)
- Troubleshooting Process Recording Charts (blank copies—minimum 3 per student per skill)
- Component Troubleshooting Tables (reference handouts for each skill)

Required PPE

Safety glasses, gloves, non-melting and non-flammable fabrics, and work boots. Electrical meters available to confirm power is off when required. Main power switch enclosure locked when not in use.

LAB 12.1

Test a Compressor

45–55 min | Proficiency | Instructor-Led Demo / Extended Practice

Learning Objectives

Upon completion, the student will be able to:

1. Identify the compressor power and control circuit components (contactor, capacitor, compressor terminals)
2. Measure and interpret contactor coil voltage and resistance
3. Test capacitor capacitance and compare to rated value
4. Explain the diagnostic logic for compressor winding and ground fault tests
5. Document findings using a Troubleshooting Process Recording Chart

Skill-Specific Materials

- Compressor Troubleshooting Table (reference handout)
- Known-bad capacitor (compressor-rated)
- Crimp connector (for open-circuit fault)

📖 Lesson Procedure

📝 Background

The compressor is the heart of any HVAC system. Compressor faults can be electrical (open/shorted windings, bad capacitor, failed contactor) or mechanical (seized bearings, internal overload). This skill teaches a systematic diagnostic approach using the Compressor Troubleshooting Table and focuses on the two most common field-serviceable electrical faults: contactor failure and capacitor failure.

On field equipment without a diagnostic panel, locate test points on the actual components:

- Contactor coil terminals (A1/A2): Trace the 24 VAC wire from the Y terminal to where it connects to the contactor coil.
- Contactor load terminals: Line voltage enters at L1/L2 from the disconnect; load side T1/T2 feeds the compressor.
- Capacitor terminals (C, Herm, Fan): On the dual-run capacitor. De-energize and discharge with a 20,000 Ω resistor before testing.
- Compressor terminals (C, S, R): Under the compressor terminal cover. Highest resistance between any two = S–R (both windings in series).

🛠️ Setup

1. Verify system is operational in cooling mode
2. Distribute Recording Charts and Compressor Troubleshooting Table
3. Review the diagnostic workflow with students before introducing any fault

📋 Procedure

The following diagnostic workflow applies to every fault scenario in this lab. Teach it once, then run each scenario through it:

1. Observe: What is running? What is not? What sounds or temperatures are abnormal? Record symptoms.
2. Consult: Refer to the Troubleshooting Table. Based on the symptom, find the first recommended test.
3. Measure: Perform the test using the correct meter setting. Record the reading.
4. Interpret: Compare the reading to the expected normal value.
5. Continue or diagnose: If normal, return to the table for the next test. If abnormal, you have found the fault.
6. Document: Record the fault found and the remedy on the Recording Chart.

📐 Measurement Interpretation Reference

Measurement	Expected Normal	Indicates Fault
Contactor coil resistance	Continuity	OL = open coil, replace contactor
Contactor coil voltage (energized)	24 VAC	0 V = no control signal from thermostat
Contactor load voltage (L1–L2)	240 VAC	0 V = no line power, check disconnect/breaker
Capacitor (Herm–C)	Rated value ±10%	OL or far out of range = failed, replace
Compressor C–S winding*	Medium Ohm Reading	OL = open
Compressor S–R winding*	Highest Ohm Reading	OL = open
Compressor C–R winding*	Lowest Ohm Reading	OL = open
Any terminal to ground*	OL (no continuity)	Any reading = ground fault

⚠️ Fault Scenarios

> Fault Scenario A: Open Contactor Coil
> Insert: Disconnect one contactor coil wire at terminal A1 or A2. A crimp connector on insulated wire makes this look intact to students.
> Symptoms: Compressor and outdoor fan stop. Indoor blower continues. Supply air temperature rises.
> Key Measurement: ____
> Diagnosis: ____
> Reset: Reconnect coil wire. System resumes immediately on next cooling call.

> Fault Scenario B: Bad Compressor Capacitor
> Insert: Shut down system. Swap the compressor run capacitor for a known-bad unit. Restart.
> Symptoms: Outdoor fan runs. Blower runs. Compressor does not start but may hum. Supply air is not cool.
> Key Measurement: The highest resistance is between Start-Run, the lowest is Common-Run, and the medium reading is Common-Start.
> Diagnosis: ____
> Reset: Shut down. Reinstall good capacitor. Restart. (5–10 min total.)

🏁 Closure

- Review completed Recording Charts
- Discuss how the same workflow applies to every skill in this lab
- Ask: What if the compressor hummed but contactor and capacitor both tested good? (Answer: proceed to winding tests)

✅ Assessment

- Correct use of multimeter for voltage, resistance, and capacitance
- Accurate interpretation of readings using the troubleshooting table
- Proper identification of the faulted component for each scenario
- Completed Recording Chart with symptoms, tests, results, and remedy
- Safe capacitor discharge procedure demonstrated

> 🔧 **Instructor Notes**
>
> Label all components on the training system before student access: service disconnect, contactor, capacitor, compressor terminals, reversing valve, defrost control board, blower motor, outdoor fan motor.
> For manual fault insertion: crimp connections without stripping wire insulation create a realistic open circuit that looks intact. Stock 2–3 known-bad capacitors for rotation. Ball valves in the liquid/suction lines are reusable across multiple skills.
> For thermistor faults: a set of fixed resistors (100 Ω and 100K Ω) can simulate out-of-range readings when substituted for the thermistor.

🔄 Equipment Flexibility

- Commercial trainers: Use provided diagnostic panel test points per manufacturer documentation. After completing each measurement, also have students locate the same test point on the actual component to reinforce field access skills.
- Field equipment: Follow the component access guidance in each skill's Background section to locate test points. Use installation/service manual documentation; create supplemental labels as needed.
- Component kits: Individual components (contactors, capacitors, thermistors) can be bench-mounted for isolated testing practice using generic diagrams.

🔬 Extended Practice

Additional Diagnostic Scenarios

Programs with fault insertion software or hardware can extend these skills with additional scenarios that are not practical to create manually, including: internal compressor winding failures (open, shorted, ground fault), ECM blower control unit failure, TXV sensing bulb charge loss, internal reversing valve leakage, and randomized multi-fault troubleshooting assessments.

The troubleshooting tables and discussion items provided with each skill cover the diagnostic logic for these additional faults, so students who complete the core manual scenarios will have the foundational skills to work through software-generated faults.

❄️ Cold Climate Consideration

In cold climates, compressor amp draw increases during heating mode—stresses capacitor and contactor over time.

Crankcase heater failure can cause liquid slugging on cold startup, tripping the internal overload repeatedly.

💡 Key Teaching Points

- Resistance measurements must be taken with power off and the component isolated
- A compressor that hums but does not start often indicates a failed capacitor or seized compressor
- Always discharge capacitors before testing
- Both windings reading OL may indicate tripped internal overload—allow the compressor to cool and retest

LAB 12.2

Test a Thermostatic Expansion Valve (TXV)

30–40 min | Proficiency | Instructor-Led Demo / Extended Practice

🎯 Learning Objectives

Upon completion, the student will be able to:

1. Record baseline operating pressures and temperatures for a normally operating system
2. Calculate superheat and subcooling from measured values
3. Identify the pressure and temperature symptoms of a restricted TXV
4. Distinguish between a TXV restriction and other refrigerant-side restrictions

📋 Skill-Specific Materials

- P-T chart for system refrigerant (R-410A and/or R-454B)
- TXV Troubleshooting Table (reference handout)

📖 Lesson Procedure

📝 Background

The TXV regulates refrigerant flow into the evaporator based on suction line superheat. When a TXV fails, it either restricts flow (high superheat, low suction pressure, frost near the valve) or fails open (low superheat, liquid floodback). This skill uses a ball valve to simulate a restriction.

TXV diagnostics are pressure and temperature-based, making this skill naturally equipment-agnostic. Connect the gauge manifold to high-side and low-side service ports, attach a pipe-clamp probe to the liquid line for subcooling and vapor line for superheat, and place a pocket thermometer in the supply register.

🛠️ Setup

1. System running in cooling mode for at least 10 minutes to stabilize
2. Gauge manifold connected; pipe-clamp probe on liquid line; pocket thermometer in supply register
3. Distribute TXV Troubleshooting Table and P-T chart
4. Verify instructor-installed liquid line ball valve is fully open

📋 Procedure

1. This skill adds a baseline comparison to the diagnostic workflow: students first record normal data, then compare to faulted data.
2. Phase 1: Establish Normal Baseline
3. Record: high-side pressure, low-side pressure, liquid line temperature, vapor line temperature, supply air temperature.
4. Calculate subcooling and superheat. Confirm readings are within manufacturer's range (typically superheat 8–12°F, subcooling 8–14°F).
5. Phase 2: Diagnose a Restriction

⚠️ Fault Scenarios

> Fault Scenario: TXV Restriction (Liquid Line Ball Valve)
> Insert: Partially close the instructor-installed liquid line ball valve (approximately 50–75% closed).
> Symptoms: Low-side pressure drops significantly. Superheat rises well above normal (20°F+). Supply air temperature rises. Frost may form near the restriction.
> Key Measurement: Compare faulted readings to baseline: superheat increase and suction pressure drop are the primary indicators.
> Diagnosis: ____
> Reset: Open ball valve fully. Allow 10 minutes to restabilize. Verify baseline returns.

🏁 Closure

- Review baseline vs. faulted data—discuss the magnitude of change
- Discuss filter drier restriction vs. TXV restriction (frost location)
- Note the sensing bulb test as a useful field technique (warm the bulb, watch for suction pressure rise)
- Disconnect gauge manifold properly

✅ Assessment

- Accurate baseline pressure and temperature readings
- Correct superheat and subcooling calculations
- Ability to identify the restriction pressure/temperature pattern
- Completed Recording Chart with baseline vs. faulted comparison

💡 Key Teaching Points

- Always establish a baseline before diagnosing—you cannot identify abnormal without knowing normal
- A restriction causes high superheat AND frost near the restricted point—these together are strongly diagnostic
- After turning off the compressor, a restricted system will equalize pressures more slowly than normal—another diagnostic indicator
- A partially blocked filter drier produces very similar symptoms—check the drier temperature drop first as the more common cause

🔧 Instructor Notes

This scenario requires 10 minutes for symptoms to develop—best as a class-wide demonstration.
Have students record baseline and faulted data side by side on their Recording Chart.
Discuss frost location to differentiate TXV restriction (frost at TXV) from filter drier restriction (frost at drier).

📐 Measurement Interpretation Reference

Measurement	Expected Normal	Indicates Fault
Superheat (normal)	8–12°F (per manufacturer)	Within range = metering device feeding correctly
Superheat (restricted)	Significantly elevated (20°F+)	Insufficient refrigerant reaching evaporator
Low-side pressure (restricted)	Noticeably lower than baseline	Restriction upstream of evaporator
Frost near metering device	None during normal operation	Pressure drop at restriction = localized freezing

❄️ Cold Climate Consideration

In heating mode, the outdoor TXV is the active metering device—testing requires outdoor unit access.
Moisture freezing at the TXV can mimic a restriction in cold climates. A nitrogen purge may clear the blockage.

LAB 12.3

Test an Electronic Thermostat

35–45 min | Proficiency | Instructor-Led Demo / Extended Practice

🎯 Learning Objectives

Upon completion, the student will be able to:

1. Identify thermostat terminal functions (R, C, Y, G, O, W, E)
2. Use a jumper wire to bypass the thermostat and isolate it as the fault source
3. Diagnose no-blower, no-reversing-valve, and no-compressor faults
4. Check transformer output voltage to diagnose a dead thermostat

📋 Skill-Specific Materials

- Electronic Thermostat Troubleshooting Table (reference handout)
- No Power to Thermostat Troubleshooting Table (reference handout)

📖 Lesson Procedure

📝 Background

The thermostat controls all system functions through low-voltage switching. The key diagnostic technique is the jumper bypass test: connecting R directly to a suspect output terminal (G, Y, or O) bypasses the thermostat's internal switching. If the component then operates, the thermostat is at fault.

On field equipment, access terminals by removing the thermostat from its wall plate. On training equipment, wiring may be accessible at a terminal block. Identify: R (24 VAC), C (common), Y (compressor), G (blower), O or B (reversing valve), W (auxiliary heat).

CRITICAL SAFETY: Never jumper R to C—this shorts the transformer and will blow the fuse or damage the transformer.

🛠️ Setup

1. System running in heating mode with stable operation
2. Distribute Thermostat Troubleshooting Tables and Recording Charts

📋 Procedure

1. All four scenarios use the same jumper bypass technique with different terminals.

⚠️ Fault Scenarios

Fault Scenario A: No Blower (G Wire Disconnected)
Insert: Disconnect the G wire at the thermostat subbase or terminal block.
Symptoms: Compressor running, outdoor fan running, blower not running.
Key Measurement: Measure voltage between C and G for 24 VAC
Test: If no voltage, place jumper R to G: if blower starts, thermostat G output has failed.
Diagnosis: ____
Reset: Reconnect G wire. Immediate.

Fault Scenario B: Reversing Valve Not Shifting (O Wire Disconnected)
Insert: Set to cooling mode. Disconnect the O/B wire.
Symptoms: System calls for cooling but produces warm air (valve stuck in heating).
Key Measurement: Measure voltage between C and O/B for 24 VAC
Test: If no voltage, place jumper R to O/B: if valve shifts (audible click, temperature change), thermostat O output has failed.
Diagnosis: ____
Reset: Reconnect O/B wire. Immediate.

Fault Scenario C: No Compressor (Y Wire Disconnected)
Insert: Disconnect the Y wire.
Symptoms: Blower running, compressor and outdoor fan not running.
Key Measurement: Measure voltage between C and Y for 24 VAC
Test: If no voltage, wait 5 minutes since compressor last ran. Place jumper R to Y: if compressor starts, thermostat Y output has failed.
Diagnosis: ____
Reset: Reconnect Y wire. Immediate (observe 5-min delay).

Fault Scenario D: No Power to Thermostat (Transformer Fault)
Insert: Pull the transformer fuse or disconnect the transformer secondary wire.
Symptoms: Thermostat display off. Nothing operates.
Key Measurement: ____
Diagnosis: ____
Reset: Replace fuse or reconnect wire. Immediate.

🏁 Closure

- Review the jumper bypass as a universal diagnostic tool
- Reinforce: NEVER jumper R to C
- Discuss the 5-minute compressor restart delay
- A dead display does not always mean a bad thermostat—check the transformer first

✅ Assessment

- Correct identification of thermostat terminal functions
- Safe use of the jumper bypass technique
- Accurate interpretation of bypass results
- Correct transformer voltage measurement
- Completed Recording Charts for each scenario

💡 Key Teaching Points

- The jumper bypass works on any thermostat-controlled system—one of the most useful field techniques
- NEVER jumper R to C
- Always wait 5 minutes before restarting a compressor
- The bypass tells you the thermostat is the problem but not why—replacement is the typical remedy

> 🔧 **Instructor Notes**
>
> Scenarios A, B, C are fast-reset wire disconnects—ideal for per-student rotation through all three in one session.
> Scenario D can be combined or run as a standalone demonstration.
> Always enforce the 5-minute compressor restart delay when bypassing Y.

LAB 12.4

Test a Reversing Valve

25–35 min | Proficiency | Instructor-Led Demo / Extended Practice

🎯 Learning Objectives

Upon completion, the student will be able to:

1. Perform the reversing valve touch test to determine if the valve has shifted
2. Measure voltage at the solenoid coil to verify the control signal
3. Test the solenoid coil for magnetism using the physical slide test
4. Interpret temperature patterns at the four reversing valve ports

📋 Skill-Specific Materials

- Reversing Valve Troubleshooting Table (reference handout)
- 5/16" wrench or adjustable wrench (for solenoid retaining screw)

📖 Lesson Procedure

📝 Background

The reversing valve (switchover valve, SOV) redirects refrigerant flow between heating and cooling. It is pilot-operated: a solenoid shifts a pilot valve that uses pressure differential to move the main slide. This skill uses a disconnected solenoid lead to simulate a coil failure.

The valve is in the outdoor unit with four refrigerant lines: A (discharge—always hot), B (suction—always cold), C (outdoor coil), D (indoor coil). In cooling: C = hot, D = cold. In heating: C = cold, D = hot. The solenoid sits on the pilot stem, held by a retaining screw.

🛠️ Setup

1. System running in cooling mode with outdoor unit front panel removed
2. Distribute Reversing Valve Troubleshooting Table
3. Prepare fault: disconnect one solenoid lead

📐 Measurement Interpretation Reference

Measurement	Expected Normal	Indicates Fault
Touch test (cooling mode)	A=Hot, B=Cold, C=Hot, D=Cold	C/D reversed = valve stuck
Solenoid voltage (at leads)	24 VAC	0 V = no signal from thermostat/DCB
Magnetism test (energized)	Strong resistance to sliding	No resistance = open coil or not energized
Solenoid coil resistance	Low resistance (manufacturer spec)	OL = open coil, replace solenoid

⚠️ Fault Scenarios

> Fault Scenario: Open Reversing Valve Solenoid
> Insert: Disconnect one solenoid lead. Valve stays in heating position while system calls for cooling.
> Symptoms: Compressor and outdoor fan running, supply air warm instead of cool. Touch test: C and D temperatures reversed from expected.
> Key Measurement: ____
> Diagnosis: ____
> Reset: Reconnect solenoid lead. System shifts to cooling within seconds.

🏁 Closure

- The touch test alone often provides the initial diagnosis in seconds
- Solenoid coil can be replaced independently of the valve body
- Internal valve leakage (cannot be manually created) is diagnosed by small temperature difference between lines A and B

✅ Assessment

- Correct execution and interpretation of the touch test
- Accurate voltage measurement at solenoid leads
- Correct magnetism test (before and after reconnection)
- Understanding of the full diagnostic sequence

💡 Key Teaching Points

- The touch test is a fast, no-instrument diagnostic
- The magnetism test confirms coil function without disconnecting wires
- A valve with power and a good coil that won't shift may have a blocked pilot tube—shut off compressor to equalize pressures and retry

> **❄️ Cold Climate Consideration**
>
> During defrost, the defrost board energizes the solenoid to briefly shift to cooling and melt outdoor coil ice. A failed solenoid prevents effective defrost.
> A stuck valve prevents defrost completion—leading to progressive ice buildup.

LAB 12.5

Test Blower Motors and Outdoor Fan

30–40 min | Proficiency | Instructor-Led Demo / Extended Practice

🎯 Learning Objectives

Upon completion, the student will be able to:

1. Diagnose a non-running indoor blower caused by a tripped indoor circuit breaker
2. Test outdoor fan capacitor capacitance and compare to rated value
3. Explain the diagnostic logic for ECM control unit failure and open motor windings
4. Recognize compressor short-cycling as a symptom of outdoor fan failure

📋 Skill-Specific Materials

- ECM Blower and Outdoor Fan Troubleshooting Tables
- Known-bad fan capacitor

📖 Lesson Procedure

📝 Background

Modern heat pumps use ECM blowers (indoor) and PSC motors (outdoor fan). This skill covers two manually reproducible faults and discusses internal failures that require fault insertion software.

Key access points:

Indoor blower: 240 VAC through dedicated indoor circuit breaker. ECM control unit receives 24 VAC from thermostat G terminal.

Outdoor fan: 240 VAC through compressor contactor. Run capacitor terminals: C (Common) and Fan on the dual-run capacitor.

🛠️ Setup

1. System operating in cooling mode
2. Distribute ECM Blower and Outdoor Fan Troubleshooting Tables

⚠️ Fault Scenarios

> Fault Scenario A: Tripped Indoor Breaker (No Blower)
> Insert: Trip the indoor circuit breaker.
> Symptoms: Blower stops. Compressor and outdoor fan may continue (separate circuit).
> Key Measurement: ____
> Diagnosis: ____
> Reset: Reset breaker.

> Fault Scenario B: Bad Outdoor Fan Capacitor
> Insert: Shut down. Swap outdoor fan capacitor for a known-bad unit. Restart.
> Symptoms: Fan does not start. Compressor starts but short-cycles within a minute (high-pressure cutout). Stops, restarts, stops again.
> Key Measurement: ____
> Diagnosis: ____
> Reset: Shut down. Reinstall good capacitor. Restart. (5–10 min total.)

🏁 Closure

- Discuss ECM diagnostics (line voltage + control signal) vs. PSC diagnostics (voltage + capacitor + windings)
- Outdoor fan failure causes rapid compressor short-cycling—time-sensitive diagnosis
- The indoor blower has its own circuit breaker—always check both

✅ Assessment

- Correct diagnosis of tripped breaker scenario
- Correct capacitor testing procedure
- Ability to connect short-cycling to fan failure as root cause
- Completed Recording Charts

💡 Key Teaching Points

- Indoor breaker is separate from outdoor disconnect—check both
- Check simplest causes first: blower door switch, tripped breaker, dirty filter
- Isolate compressor wires before testing fan motor to avoid reading windings in parallel

> **🔧 Instructor Notes**
>
> Scenario A is instant—ideal for per-student rotation.
> Scenario B requires system shutdown for the capacitor swap—best as a class-wide demonstration or once per rotation group.

> **❄️ Cold Climate Consideration**
>
> ECM blowers are common in cold climate systems for variable airflow.
> Dirty filters are a common cause of tripped indoor breakers—emphasize preventive maintenance.

LAB 12.6

Test a Defrost Control

35–45 min | Proficiency | Instructor-Led Demo / Extended Practice

🎯 Learning Objectives

Upon completion, the student will be able to:

1. Initiate a forced defrost cycle and observe the system's response
2. Measure defrost control board terminal voltages during normal heating and during defrost
3. Identify what changes during defrost: reversing valve shifts, outdoor fan stops, auxiliary heat may activate
4. Interpret defrost control board LED fault codes
5. Test defrost thermistor resistance and compare to temperature-resistance chart

📋 Skill-Specific Materials

- Defrost control board shorting bar or jumper wire
- Defrost Control Board LED Fault Code chart (from manufacturer documentation)
- Defrost thermistor temperature-resistance chart (from manufacturer documentation)
- Resistors for thermistor substitution (100 Ω and 100K Ω)

📖 Lesson Procedure

📝 Background

In heating mode, the outdoor coil accumulates frost. The defrost control board monitors an ambient thermistor and a coil thermistor. When conditions indicate ice buildup, the board initiates defrost: the reversing valve shifts to cooling briefly, the outdoor fan stops, and auxiliary heat strips (if equipped) activate.

Key access points:

Defrost control board: In the outdoor unit. Common terminals: Y, O1, O2, R, B, X2, Yo. FRC DFT and COM pins for forced defrost initiation.

Thermistors: Trace wires from the board to the ambient sensor (outdoor airstream) and coil sensor (on the outdoor coil).

🛠️ Setup

1. System running in heating mode for at least 5 minutes
2. Outdoor unit front panel removed
3. Pipe-clamp probe on the outdoor coil
4. Gauge manifold connected if available (optional—for pressure observation)
5. Distribute LED fault code chart and temperature-resistance chart

Procedure

1. This skill has three phases: observing defrost, diagnosing a thermistor fault, and verifying thermistor readings.
2. Phase 1: Normal Heating and Forced Defrost
3. Short the FRC DFT and COM pins to force defrost. Observe: reversing valve shifts (click), outdoor fan stops, auxiliary heat may activate, outdoor coil warms.
4. Defrost terminates based on manufacturer's defrost temp setpoint or time.
5. Note: Multiple forced defrost cycles are expected during this skill if the first terminates before students finish observations.
6. Phase 2: Thermistor Faults
7. Run Fault Scenarios A and B below (Ambient Thermistor Fault and Coil Thermistor Fault). For each, observe the LED fault code on the defrost board, look up the code in the manufacturer's chart, and document the diagnosis on the Recording Chart.
8. Phase 3: Verify Thermistor Readings
9. De-energize. Disconnect ambient thermistor from board.
10. Compare to manufacturer's temperature-resistance chart. OL = open (failed). Significantly off-chart = out of calibration, replace.
11. Reconnect. Restore normal operation.

Fault Scenarios

> Fault Scenario A: Ambient Thermistor Fault
> Insert: De-energize. Disconnect the ambient thermistor wire from the defrost board (or substitute a 100 Ω resistor). Re-energize.
> Symptoms: Check the manufacturer's defrost board LED table. Example: flashes 1 time for defrost. System enters timed defrost mode (every 60 minutes regardless of conditions).
> Key Measurement: Check the manufacturer's LED fault code table. Example: 1 flash = ambient temperature sensor out of range.
> Diagnosis: ____
> Reset: De-energize. Reconnect thermistor. Re-energize. LED clears.

Fault Scenario B: Coil Thermistor Fault
Insert: De-energize. Disconnect coil thermistor wire (or substitute 100 Ω resistor). Re-energize.
Symptoms: Defrost board LED flashes 2 times. System enters timed defrost mode.
Key Measurement: LED fault code: 2 flashes = coil temperature sensor out of range.
Diagnosis: ____
Reset: De-energize. Reconnect. Re-energize. LED clears.

🏁 Closure

- Review voltage differences between normal heating and defrost
- LED fault codes are a first-line diagnostic—always check the board before replacing components
- A defrost system that never activates will eventually ice over the outdoor coil completely
- NTC thermistors: resistance decreases as temperature increases

✅ Assessment

- Correct identification of defrost board terminals
- Accurate voltages during normal heating and defrost
- Ability to initiate forced defrost and describe the response
- Correct LED fault code interpretation
- Accurate thermistor resistance measurement and chart comparison

💡 Key Teaching Points

- During defrost: reversing valve shifts, outdoor fan stops, auxiliary heat activates
- Defrost terminates on manufacturer's coil temperature defrost temp setpoint or max time, not visual ice clearance
- LED codes provide specific diagnostics—always check before replacing
- NTC resistance decreases as temp increases—the chart is essential
- Common failures: rodent damage to thermistor wires, sensor displaced from coil, board relay failure

🔧 Instructor Notes

Both thermistor faults are moderate-speed resets—they require system shutdown and outdoor unit access but no part swaps.
A resistor substitution box makes this faster than disconnecting and reconnecting the actual thermistor wires each time.
Point out the LED fault codes explicitly—many technicians miss these because they don't know to look at the board.

❄️ Cold Climate Consideration

Defrost diagnostics are among the most critical skills for Massachusetts cold climate service.
Cold climate heat pumps use demand-based defrost—accurate thermistor readings are essential.
Low-ambient lockout may activate during extreme cold snaps.
Not all cold climate units have heat strips—during defrost, supply air will temporarily drop. This is normal.

LAB 13

Electronic Expansion Valves

eLearning

Electronic expansion valves (EEVs) are the primary metering device in mini-split and variable-capacity heat pump systems. Unlike thermostatic expansion valves (TXVs), EEVs are controlled electronically by the system's inverter board, allowing precise refrigerant flow regulation across a wide range of operating conditions. Students should understand EEV operation conceptually before proceeding to the mini-split labs (Labs 15–20).

Suggested Supplemental Activities

- Review eLearning content on EEV principles of operation, stepper motor control, and comparison to TXV metering
- If available, use a bench-mounted EEV display project (e.g., ACServiceTech EEV training project) to demonstrate stepper motor operation and valve positioning
- Discuss how EEV control differs from TXV control: electronic vs. mechanical feedback, inverter board commands vs. sensing bulb pressure, and implications for troubleshooting

💡 Key Teaching Points

- EEVs use a stepper motor to precisely position the valve—the inverter board determines the position based on system sensor data, not a mechanical sensing bulb
- Because EEVs are electronically controlled, many EEV faults present as error codes on the indoor unit display rather than as pressure/temperature anomalies
- EEV troubleshooting in the field typically involves checking the stepper motor coil resistance, verifying the control signal from the inverter board, and confirming the valve is not mechanically stuck

❄️ Cold Climate Consideration

EEVs (also called LEVs or AEVs) are increasingly standard in cold climate heat pumps because they can modulate precisely across a wide range of operating conditions.
Unlike TXVs, EEVs are electronically controlled and can respond to multiple inputs (outdoor temperature, indoor load, compressor speed) for optimal performance in extreme cold.

LAB 14

Troubleshooting Residential Heat Pump Systems

40-Hour Pathway | Instructor-Led Demonstration | Extended Practice

This lab covers system-level troubleshooting using flowcharts and troubleshooting tables. Where Lab 12 focused on diagnosing individual components, this lab teaches students to diagnose system symptoms (no cooling, insufficient cooling, no heating, insufficient heating, short cycling, system cut-out) by following a structured decision tree from symptom to root cause.

Each skill focuses on manually reproducible fault scenarios. The diagnostic approach follows the troubleshooting flowchart for each symptom category, narrowing from system-level observation to component-level testing.

Required Components/Systems

Residential ducted heat pump training system (operational) with full diagnostic access. Ball valves pre-installed in liquid and suction lines. Gauge manifold access ports available. All components from Lab 12 accessible.

Required Diagnostic Tools

- Digital multimeter (AC voltage, DC voltage, resistance, capacitance)
- Clamp-on ammeter
- Gauge manifold with hoses and low-loss ball valve adapters
- Pipe-clamp temperature probe and digital thermometer
- Pocket thermometer
- Jumper wire with insulated clips
- 20,000 Ω resistor (for capacitor discharge)
- Troubleshooting Process Recording Charts (minimum 5 per student per skill)

Required PPE

Safety glasses, gloves, non-melting and non-flammable fabrics, and work boots. Electrical meters available to confirm power is off when required. Main power switch enclosure locked when not in use.

Equipment Flexibility

- Commercial trainers: Use provided diagnostic panel test points per manufacturer documentation. After completing each measurement, also have students locate the same test point on the actual component.
- Field equipment: Follow the component access guidance in each skill's Background section. Use installation/service manual documentation; create supplemental labels as needed.
- Component kits: Individual components can be bench-mounted for isolated testing practice using generic diagrams.

Instructor Notes

- This lab builds directly on Lab 12. Students should be comfortable with the diagnostic workflow and individual component tests before attempting system-level troubleshooting.
- Each skill uses a troubleshooting flowchart specific to the symptom category. These flowcharts guide students from the initial symptom through a series of decision points to the root cause. Distribute the appropriate flowchart at the start of each skill.
- Manual fault insertion techniques are the same as Lab 12: wire disconnects, ball valve adjustments, breaker trips, capacitor swaps, thermistor disconnects.

Extended Practice

- Additional Diagnostic Scenarios
- Programs with fault insertion software or hardware can extend these skills with additional scenarios that are not practical to create manually, including: randomized multi-fault troubleshooting in both practice and timed assessment modes, software-generated faults from the full fault library, and multi-component failure scenarios.
- **Reversing valve stuck in cooling position during a heating call (Lab 14.3):** with the system in heating mode, the instructor disconnects one reversing valve solenoid lead. Students follow the No Heating flowchart, perform the touch test at the outdoor unit (expected heating pattern: A=hot, B=cold, C=cold, D=hot), and confirm with a 24 VAC measurement at the solenoid leads. Reset by reconnecting the lead — valve shifts within seconds. Suitable for programs with extra time, upskilling incumbent workers, or programs running troubleshooting as a student rotation rather than an instructor-led demonstration.
- The troubleshooting tables and discussion items provided with each skill cover the diagnostic logic for these additional faults.

LAB 14.1

Troubleshoot No Cooling

45–55 min | Proficiency | Instructor-Led Demo / Extended Practice

🎯 Learning Objectives

Upon completion, the student will be able to:

1. Follow the No Cooling Troubleshooting Flowchart from symptom to root cause
2. Systematically narrow the fault from system-level symptom to component-level diagnosis
3. Diagnose a no-cooling condition caused by a thermostat output failure
4. Document the complete troubleshooting process on a Recording Chart

📋 Skill-Specific Materials

- No Cooling Troubleshooting Flowchart and Tables (reference handout)

📖 Lesson Procedure

📝 Background

A no-cooling complaint means the system is not producing cool air when calling for cooling. Possible root causes span the entire system: thermostat not calling correctly, compressor not running, outdoor fan not running, refrigerant flow restriction, or reversing valve stuck in heating. The No Cooling Flowchart provides a structured path through these possibilities.

🛠️ Setup

1. Verify system is operating normally in cooling mode before introducing faults
2. Distribute No Cooling Troubleshooting Flowchart and Recording Charts
3. Gauge manifold connected for pressure observation

📋 Procedure

1. Follow the diagnostic workflow from Lab 12.1. This skill applies it at the system level using the flowchart.

⚠️ Fault Scenarios

> Fault Scenario A: No Cooling — Thermostat G Fault (Blower Not Running)
> Insert: Disconnect the G wire at the thermostat subbase.
> Symptoms: System calling for cooling. Compressor and outdoor fan running. Blower not running. No supply air at the registers.
> Key Measurement: Follow flowchart: pretest confirms blower not running. Check thermostat fan setting (correct). Jumper R to G—blower starts, confirming thermostat fault.
> Diagnosis: ____
> Reset: Reconnect G wire. Immediate.

> Fault Scenario B: No Cooling — Reversing Valve Stuck in Heating
> Insert: Disconnect one reversing valve solenoid lead.
> Symptoms: System calling for cooling. Compressor running, fan running, blower running. Supply air is warm (system is heating instead of cooling).
> Key Measurement:
> Diagnosis: ____
> Reset: Reconnect solenoid lead. Immediate.

🏁 Closure

- Review how the flowchart narrowed the diagnosis from "no cooling" to a specific component
- Discuss how different root causes produce different patterns on the flowchart

✅ Assessment

- Correct use of the troubleshooting flowchart to reach the diagnosis
- Completed Recording Chart documenting the full path from symptom to remedy
- Ability to articulate why each test was performed and what it ruled out

LAB 14.2

Troubleshoot Insufficient Cooling

35–45 min | Proficiency | Instructor-Led Demo / Extended Practice

🎯 Learning Objectives

Upon completion, the student will be able to:

1. Follow the Insufficient Cooling Troubleshooting Flowchart
2. Compare operating pressures and temperatures to baseline values to identify performance degradation
3. Diagnose a refrigerant flow restriction using pressure-temperature analysis

📋 Skill-Specific Materials

- Insufficient Cooling Troubleshooting Flowchart and Tables
- P-T chart for system refrigerant

📖 Lesson Procedure

📝 Background

Insufficient cooling means the system operates but does not reach the desired temperature. The system runs, the blower moves air, but comfort is not achieved. Root causes include refrigerant restrictions, dirty coils, incorrect charge, or airflow problems. This skill uses pressure-temperature analysis to identify a restriction.

🛠️ Setup

1. System running in cooling mode for 10+ minutes to establish baseline
2. Gauge manifold connected; pipe-clamp probe on liquid line; pocket thermometer in supply register
3. Record baseline pressures, temperatures, superheat, and subcooling before introducing fault

⚠️ Fault Scenarios

> Fault Scenario: Refrigerant Flow Restriction (Ball Valve)
> Insert: Partially close the liquid line ball valve (50–75% closed).
> Symptoms: System continues running but supply air temperature rises. Low-side pressure drops. Superheat increases significantly. Frost may form near the restriction.
> Key Measurement: Compare faulted readings to baseline: superheat increase and low-side pressure drop are primary indicators. Follow flowchart to "Refrigerant flow restriction" branch.
> Diagnosis: ____
> Reset: Open ball valve fully. Allow 10 minutes to restabilize. Verify baseline returns.

Closure

- Review baseline vs. faulted data comparison
- Discuss how insufficient cooling differs from no cooling on the flowchart—the system runs, but performance is degraded

Assessment

- Accurate baseline and faulted pressure/temperature readings
- Correct superheat and subcooling calculations
- Ability to follow the flowchart to the restriction diagnosis

Key Teaching Points

- System-level troubleshooting starts with observation and the flowchart—not by jumping to component tests
- The flowchart eliminates possibilities systematically—each test either confirms or rules out a branch
- No-cooling symptoms can have many root causes—the flowchart ensures you don't miss one

Instructor Notes

Both scenarios are fast-reset faults. An instructor can cycle through students efficiently.
Emphasize that the flowchart guides the sequence—students should follow it rather than jumping to conclusions.

Cold Climate Consideration

In cold climates, a no-cooling call during shoulder season may actually be a reversing valve issue from the previous heating season.
Check defrost board relay contacts as a potential cause of stuck reversing valve before replacing the solenoid.

LAB 14.3

Troubleshoot No Heating

40–50 min | Proficiency | Instructor-Led Demo / Extended Practice

🎯 Learning Objectives

Upon completion, the student will be able to:

1. Follow the No Heating Troubleshooting Flowchart from symptom to root cause
2. Diagnose a no-heating condition caused by a refrigerant flow restriction
3. Recognize the symptoms and diagnostic approach for a reversing valve that has not shifted
4. Differentiate between thermostat, reversing valve, and compressor causes of no heating

📋 Skill-Specific Materials

- No Heating Troubleshooting Flowchart and Tables

📖 Lesson Procedure

📝 Background

A no-heating complaint means the system is not producing warm air when calling for heating. In a heat pump, heating requires the reversing valve to be in the correct position, the compressor to run, and the outdoor coil to function as the evaporator. The No Heating Flowchart guides diagnosis through these elements.

🛠️ Setup

1. System operating in heating mode for 10+ minutes to establish baseline
2. Gauge manifold connected; pipe-clamp probe on suction line; pocket thermometer in supply register
3. Record baseline pressures, temperatures, superheat, and subcooling before introducing fault
4. Distribute No Heating Troubleshooting Flowchart and Recording Charts

⚠️ Fault Scenarios

> Fault Scenario: Refrigerant Flow Restriction (Ball Valve)
> Insert: Partially close the liquid line ball valve (50–75% closed).
> Symptoms: System continues running but supply air temperature falls below normal (heat pump cannot deliver heat). Low-side pressure drops. Superheat increases significantly. Frost may form near the restriction on the indoor coil side.
> Key Measurement: Compare faulted readings to baseline: superheat increase and low-side pressure drop are primary indicators. Follow flowchart to "Refrigerant flow restriction" branch.
> Diagnosis: ____
> Reset: Open ball valve fully. Allow 10 minutes to restabilize. Verify baseline returns.

🔧 Instructor Notes

- **Reversing valve discussion (5–10 min, instructor-led):** After running the refrigerant restriction scenario above, take a few minutes to walk students verbally through how a stuck reversing valve presents on a no-heat call.
- In Massachusetts, a stuck reversing valve is one of the most common causes of "no heat" service tickets — the homeowner reports cold air from the supply registers in the middle of winter.
- The diagnostic technique is identical to what students learned in Lab 14.1 Scenario B and in depth in Lab 12.4: perform the touch test on the four refrigerant lines at the outdoor unit, then measure 24 VAC at the solenoid leads.
- In heating mode the expected pattern is A=hot, B=cold, C=cold, D=hot — if C and D are reversed, the valve has not shifted.
- The most common causes are an open solenoid coil, a stuck pilot valve, or — in our climate — a defrost board relay that has failed to energize the solenoid during defrost recovery.
- No fault insertion is required for this discussion; programs with extra time and fault-insertion capability can add the hands-on scenario described in the Lab 14 Extended Practice block.

🏁 Closure

- Compare the No Heating flowchart to the No Cooling flowchart—discuss the parallels
- Discuss how reversing valve position determines heating vs. cooling

✅ Assessment

- Correct use of the No Heating flowchart
- Completed Recording Chart for each scenario
- Understanding of how the same component (reversing valve) affects both heating and cooling

LAB 14.4

Troubleshoot Insufficient Heating

35–45 min | Proficiency | Instructor-Led Demo / Extended Practice

🎯 Learning Objectives

Upon completion, the student will be able to:

1. Follow the Insufficient Heating Troubleshooting Flowchart
2. Diagnose insufficient heating caused by reduced airflow
3. Measure temperature differential across the indoor coil to assess heating performance

📋 Skill-Specific Materials

- Insufficient Heating Troubleshooting Flowchart and Tables
- Dirty or restrictive air filter (for fault simulation)

📖 Lesson Procedure

📝 Background

Insufficient heating means the system runs in heating mode but cannot maintain the desired temperature. Causes include reduced airflow (dirty filter, blocked return), refrigerant charge issues, outdoor coil icing (defrost failure), or supplemental heat not activating.

🛠️ Setup

1. System operating in heating mode
2. Record baseline supply air temperature and return air temperature for reference
3. Distribute Insufficient Heating Flowchart

⚠️ Fault Scenarios

> Fault Scenario: Dirty Air Filter (Restricted Airflow)
> Insert: Install a severely dirty or restrictive filter in the indoor unit return air path.
> Symptoms: System runs but supply air temperature lower than expected. Temperature differential (return minus supply) lower than baseline. System may short-cycle or ice up.
> Key Measurement: Check filter visibly—dirty and restricted. Measure return and supply air temperatures.
> Diagnosis: ____
> Reset: Remove dirty filter. Install clean filter or run without filter to verify performance recovers.

Closure

- Discuss how reduced airflow affects both heating and cooling performance
- Emphasize that a dirty filter is the most common cause of performance complaints in the field

Assessment

- Correct use of the Insufficient Heating flowchart
- Understanding of the airflow-capacity relationship
- Completed Recording Chart

LAB 14.5

Troubleshoot Short Cycling

40–50 min | Proficiency | Instructor-Led Demo / Extended Practice

Learning Objectives

Upon completion, the student will be able to:

1. Follow the Short Cycling (Frequent Cycling) Troubleshooting Flowchart
2. Identify compressor short-cycling caused by high discharge pressure from outdoor fan failure
3. Distinguish between thermostat-caused cycling and pressure-caused cycling

Skill-Specific Materials

- Short Cycling Troubleshooting Flowchart and Tables
- Known-bad fan capacitor (from Lab 12)

Lesson Procedure

Background

Short cycling occurs when the compressor repeatedly starts and stops in rapid succession. Common causes include: thermostat differential set too low, thermostat affected by stray heat sources, outdoor fan failure causing high discharge pressure (high-pressure cutout trips), or internal compressor overload tripping. The flowchart guides diagnosis from the most common to the most complex cause.

🛠️ Setup

1. System operating in cooling or heating mode
2. Distribute Short Cycling Flowchart

⚠️ Fault Scenarios

> Fault Scenario: Bad Outdoor Fan Capacitor (High-Pressure Cutout)
> Insert: Shut down. Swap outdoor fan capacitor for a known-bad unit. Restart system in cooling mode.
> Symptoms: System starts. Compressor and indoor blower run. Outdoor fan does not start. Within 30–60 seconds, discharge pressure rises above cutout setpoint and system shuts down. System may restart after pressure equalizes, then repeat the cycle.
> Key Measurement: Monitor discharge pressure—exceeds normal operating range, triggers cutout, pressure drops as compressor shuts off, system restarts.
> Diagnosis: ____
> Reset: Shut down. Reinstall good capacitor. Restart. (5–10 min total.)

🏁 Closure

- Discuss the cause-and-effect chain from fan failure to compressor short-cycling
- Distinguish between mechanical short-cycling (pressure cutout) and thermostat short-cycling (differential too low)—the timing pattern is different

✅ Assessment

- Correct use of the Short Cycling flowchart
- Ability to trace the root cause chain from symptom back to failed component
- Completed Recording Chart

LAB 14.6

Troubleshoot System Cut-Out

35–45 min | Proficiency | Instructor-Led Demo / Extended Practice

🎯 Learning Objectives

Upon completion, the student will be able to:

1. Follow the System Cut-Out Troubleshooting Flowchart
2. Diagnose a system cut-out caused by a refrigerant restriction activating the low-pressure cutout
3. Differentiate between high-pressure and low-pressure cutout conditions

📋 Skill-Specific Materials

- System Cut-Out Troubleshooting Flowchart and Tables

📖 Lesson Procedure

📝 Background

A system cut-out occurs when a safety control device (high-pressure cutout, low-pressure cutout, or other safety switch) shuts down the system. Unlike short cycling, the system may not restart automatically. Root causes include refrigerant restrictions (low-pressure cutout), condenser blockage (high-pressure cutout), or loss of refrigerant charge (low-pressure cutout). Terminology note: OEM terminology varies. Some manufacturers call this a lockout or compressor lockout, while others may describe the event as a cut-out, protection cut-out, safety trip, fault, or abnormality. In general, a cutout is the protective trip/action, while a lockout is the latched no-restart state that can follow. Refer to the equipment service manual for the manufacturer's preferred term and reset procedure.

🛠️ Setup

1. System operating in cooling mode
2. Gauge manifold connected for pressure observation
3. Distribute System Cut-Out Flowchart

⚠️ Fault Scenarios

> Fault Scenario: Refrigerant Restriction Activating Low-Pressure Cutout
> Insert: Partially close the liquid line ball valve (50–75% closed).
> Symptoms: System runs normally for 5–10 minutes. Supply air temperature rises slightly. Low-side pressure drops progressively. Compressor shuts down and does not restart automatically (low-pressure cutout trips).
> Key Measurement: Monitor low-side pressure—drops below cutout setpoint (typically 30–50 psig depending on refrigerant), compressor shuts off and stays off.
> Diagnosis: ____
> Reset: Open ball valve fully. Wait 5 minutes for pressures to equalize. System should restart automatically.

🏁 Closure

- Review the gauge pressure behavior leading to the cutout
- Discuss how low-pressure vs. high-pressure cutouts point to different root causes
- Note that refrigerant charge loss (leak) produces similar low-pressure symptoms—leak detection should follow if no restriction is found

✅ Assessment

- Correct use of the System Cut-Out flowchart
- Ability to read and interpret gauge pressures during the fault
- Understanding of the difference between high-pressure and low-pressure cutout causes
- Completed Recording Chart

LAB 15

Introduction to Residential Mini-Split Heat Pump Systems

40-Hour Pathway

This lab introduces students to the physical components and basic operation of residential mini-split heat pump systems. These are hands-on orientation skills performed on any available mini-split system.

Required Components/Systems

Residential mini-split heat pump system (operational or non-operational) with accessible indoor and outdoor units, disconnect, and thermostat/remote control.

Required Materials

- Manufacturer's installation manual or component diagram
- Labels/tags for component identification

Required PPE

Safety glasses, gloves, non-melting and non-flammable fabrics, and work boots. Electrical meters available to confirm power is off when required. Main power switch enclosure locked when not in use.

Equipment Flexibility

- Commercial trainers: Use provided equipment documentation; labeling typically matches manufacturer materials.
- Field equipment: Use installation/service manual documentation. Create supplemental labels as needed for student orientation.
- Component kits: Individual components can be bench-mounted for isolated practice using generic diagrams.

LAB 15.1

Identify Mini-Split System Components

15–20 min | Proficiency | 40-Hour Pathway

🎯 Learning Objectives

Upon completion, the student will be able to:

1. Identify the major components of a mini-split heat pump system (outdoor unit, indoor unit, refrigerant lines, disconnect, thermostat/remote)
2. Describe the function of each major component in the refrigerant and electrical circuits
3. Locate service access points on a mini-split system

📖 Lesson Procedure

📝 Background

Mini-split heat pump systems differ from conventional ducted systems in several ways: the indoor and outdoor units are connected by refrigerant lines rather than ductwork, the indoor unit delivers conditioned air directly to the space, and the system typically uses an inverter-driven compressor with electronic expansion valves (EEVs). This skill introduces students to the physical layout and component identification.

Key components to identify: outdoor unit (compressor, condenser coil, outdoor fan, inverter board, EEV, service valves), indoor unit (evaporator coil, indoor fan, air filter, drain pan, thermistors), refrigerant lines (liquid line, vapor line), electrical connections (disconnect, power wiring, communication wiring between indoor and outdoor units), and thermostat/remote control.

🛠️ Setup

1. Ensure students have visual access to both indoor and outdoor units
2. If possible, remove access panels to expose internal components
3. Distribute component diagrams or manufacturer documentation

📋 Procedure

Guide students through a walk-around of the system, identifying each component:

1. Outdoor unit: Locate and identify the compressor, condenser coil, outdoor fan, inverter control board, EEV, service valves (liquid and vapor), and service disconnect.
2. Indoor unit: Locate and identify the evaporator coil, indoor blower fan, air filter, condensate drain pan and line, thermistors (room temp, coil temp), and communication wiring.
3. Refrigerant lines: Identify the liquid line (smaller diameter) and vapor line (larger diameter, insulated). Trace their path from outdoor to indoor unit.
4. Electrical connections: Identify the power disconnect, power wiring to the outdoor unit, and the communication cable between indoor and outdoor units.
5. Thermostat/remote: Identify the control device (wired wall mount, wireless remote, or both). Note that mini-splits typically do not use the standard R/Y/G/O thermostat wiring—they use a proprietary communication protocol.
6. Have students label each component using tags or labels provided.

🏁 Closure

- Quiz students on component locations without referring to the diagram
- Discuss the key differences between mini-split and ducted systems: no ductwork, inverter compressor, EEV, proprietary communication wiring

✅ Assessment

- Correct identification of all major components on the training system
- Completed component identification worksheet
- Verbal description of at least three component functions

💡 Key Teaching Points

- Mini-splits use proprietary communication wiring between indoor and outdoor units—not standard thermostat wiring
- The inverter board controls compressor speed, EEV position, and fan speed—it is the "brain" of the system
- Service valves on mini-splits are typically Schrader, located on the outdoor unit

❄️ **Cold Climate Consideration**

Cold climate mini-splits may have a base pan heater in the outdoor unit to prevent ice accumulation—locate and identify this component if present.

Some cold climate models have a separate defrost thermistor on the outdoor coil—identify it during the component walkthrough.

LAB 15.2

Start Up and Shut Down a Mini-Split System

15–20 min | Proficiency | 40-Hour Pathway

🎯 Learning Objectives

Upon completion, the student will be able to:

1. Perform a safe startup sequence for a mini-split heat pump
2. Verify system operation in cooling and heating modes
3. Perform a safe shutdown sequence including lockout/tagout

📋 Skill-Specific Materials

- Lockout/tagout kit
- Manufacturer's operating manual

📖 Lesson Procedure

📝 Background

Proper startup and shutdown procedures protect both the technician and the equipment. Mini-split systems have specific startup requirements: the disconnect must be energized before using the thermostat, and many systems have a startup delay (3–5 minutes) before the compressor begins operating. Understanding these sequences prevents unnecessary service calls for "system not working" complaints.

🛠️ Setup

1. System in shutdown state with disconnect off and lockout applied
2. Distribute manufacturer's operating manual

📋 Procedure (Please Refer to Equipment Manufacturer Documentation)

Startup Sequence

1. Remove lockout/tagout from the disconnect.
2. Energize the disconnect (set to On position).
3. Using the thermostat or remote, set the system mode to Cooling and set the temperature below the current room temperature.
4. Wait for the startup delay (typically 3–5 minutes). Observe: indoor fan should start, then compressor and outdoor fan.
5. Verify operation: feel cool air from the indoor unit, confirm outdoor fan is running, listen for compressor operation.

Shutdown Sequence

1. Using the thermostat or remote, set the system to Off.
2. Wait for the system to complete its shutdown cycle (fan may continue running briefly).
3. Set the disconnect to Off.
4. Apply lockout/tagout to the disconnect.

🏁 Closure

- Review the startup delay—discuss why it exists (compressor protection, pressure equalization)
- Discuss common "false alarm" service calls from customers who cycle power and don't wait for the startup delay

✅ Assessment

- Correct startup and shutdown sequence
- Proper application of lockout/tagout
- Verification of system operation in at least one mode

💡 Key Teaching Points

- A 3–5 minute startup delay is a compressor protection feature—it allows pressures to equalize before the compressor starts
- Always use lockout/tagout before performing any service—even on low-voltage systems
- The indoor fan may start before the compressor—this is normal and does not indicate a fault

LAB 16

Mini-Split Heat Pump Operation

40-Hour Pathway

This lab covers the operational controls and maintenance procedures for mini-split heat pump systems. Students learn to adjust comfort settings, operate the system in different modes, use the emergency operation switch, and perform a basic maintenance inspection.

🔄 Equipment Flexibility

- Commercial trainers: Use provided equipment documentation; labeling typically matches manufacturer materials.
- Field equipment: Use installation/service manual documentation. Create supplemental labels as needed for student orientation.
- Component kits: Individual components can be bench-mounted for isolated practice using generic diagrams.

LAB 16.1

Adjust Mini-Split Comfort Settings

15–20 min | Proficiency | 40-Hour Pathway

🎯 Learning Objectives

Upon completion, the student will be able to:

1. Navigate the thermostat/remote control interface to adjust temperature setpoint, fan speed, and airflow direction
2. Set and cancel timer functions
3. Identify the available operating modes (Cool, Heat, Dry, Fan, Auto)

📖 Lesson Procedure

📝 Background

Mini-split controls offer more adjustment options than conventional thermostats: temperature setpoint, fan speed (multiple levels plus Auto), airflow direction (vane angle and swing), operating mode (Cool, Heat, Dry, Fan Only, Auto), and timer functions. They come in two types, hard-wired and remote. Familiarity with these controls is essential for both system operation and customer education.

🛠️ Setup

1. System operational in heating and cooling modes
2. Provide each student or group with a remote control

📋 Procedure

1. Set the operating mode to Cooling. Adjust temperature to 72°F. Set fan speed to Auto. Observe indoor unit response.
2. Change fan speed through each available level (Low, Medium, High, Auto). Observe and feel the airflow change at each level.
3. Adjust the airflow direction (vane angle). If the system supports swing mode, activate it and observe.
4. Set a 30-minute timer. Verify the timer indicator appears on the display. Cancel the timer.
5. Switch to each operating mode (Heat, Dry, Fan Only, Auto) and observe the system response. Note the indoor unit display changes for each mode.

🏁 Closure

- Review the available modes and their purposes: Dry mode for some dehumidification, Fan Only for air circulation, Auto for automatic mode selection
- Discuss how to educate a homeowner on proper remote control use

✅ Assessment

- Correct navigation of all remote control functions
- Understanding of each operating mode's purpose
- Ability to set and cancel timer functions

💡 Key Teaching Points

- Dry mode reduces humidity by running the compressor at low speed with minimal fan—it does not provide significant cooling. It does not work as well as a dehumidifier.
- Auto mode allows the system to select heating or cooling based on the room temperature vs. setpoint
- Fan speed affects both comfort and efficiency—Auto is typically the best default for balanced performance

LAB 16.2

Operate a Mini-Split in Heating and Cooling Modes

20–25 min | Proficiency | 40-Hour Pathway

🎯 Learning Objectives

Upon completion, the student will be able to:

1. Operate the system in cooling mode and verify cool air delivery
2. Switch to heating mode and verify warm air delivery
3. Observe system behavior during mode changeover including compressor restart delay

📋 Skill-Specific Materials

- Digital thermometer or pipe-clamp probe

📖 Lesson Procedure

📝 Background

Switching between heating and cooling modes on a mini-split involves the reversing valve changing position and the system recalibrating pressures and EEV position. There is typically a 3–5 minute delay during the transition. Understanding this behavior prevents false "system not working" diagnoses.

🛠️ Setup

1. System operating in cooling mode for at least 5 minutes

📋 Procedure

1. Confirm cooling operation: measure supply air temperature (should be below room temperature). Record reading.
2. Switch to heating mode using the remote. Set temperature well above current room temperature.
3. Observe the transition: indoor fan may stop briefly, compressor may cycle off for the restart delay, then restart in the opposite direction.
4. Wait for heating to stabilize (5–10 minutes). Measure supply air temperature (should be above room temperature). Record reading.
5. Switch back to cooling mode and observe the reverse transition.

🏁 Closure

- Discuss the mode changeover delay and why it exists (pressure equalization, compressor protection)
- Compare supply air temperatures in heating vs. cooling mode

✅ Assessment

- Successful operation in both modes
- Accurate temperature measurements
- Understanding of mode changeover behavior

💡 Key Teaching Points

- The 3–5 minute changeover delay is normal—do not diagnose it as a fault
- Mini-split supply air temperatures vary more than ducted systems because the air is not mixed in ductwork
- In heating mode, supply air temperature decreases as outdoor temperature drops—this is normal for a heat pump

> **❄️ Cold Climate Consideration**
>
> In cold climates, heating mode supply air temperature may be significantly lower than what customers expect compared to a furnace.
> Cold climate mini-splits maintain heating capacity to much lower outdoor temperatures than conventional heat pumps—but supply air temp still drops.

LAB 16.3

Use the Emergency Operation Switch

20–25 min | Proficiency | 40-Hour Pathway

🎯 Learning Objectives

Upon completion, the student will be able to:

1. Locate and activate the emergency operation switch on the indoor unit
2. Operate the system in emergency cooling and emergency heating modes
3. Explain when emergency operation is used and its limitations

📖 Lesson Procedure

📝 Background

Most mini-split indoor units have an emergency operation switch (sometimes called a forced operation or manual operation button) that allows basic cooling or heating without the remote control. This is used when the remote is lost, broken, or has dead batteries. Emergency mode typically runs at a fixed setpoint and fan speed.

🛠️ Setup

1. System in standby (powered but not actively running)

📋 Procedure

1. Locate the emergency operation switch on the indoor unit. It is typically behind a small panel on the unit's front face or on the side.
2. Press the emergency switch once. Put the system into emergency cooling mode. Observe the indoor unit indicator lights—they will display a specific pattern indicating emergency mode.
3. Allow the system to run for 3–5 minutes. Verify cool air delivery.
4. Press the switch again. Depending on the manufacturer, subsequent presses cycle through: emergency heating, off, or back to emergency cooling. Operate in emergency heating mode and verify warm air.
5. Press the switch to turn the system off. Resume normal operation with the remote control.

Closure

- Discuss when emergency operation is appropriate: lost remote, dead batteries, initial commissioning testing
- Note the limitations: fixed setpoint, fixed fan speed, no timer or schedule functions

Assessment

- Correct location of the emergency switch
- Successful operation in emergency cooling and heating
- Understanding of emergency mode limitations

Key Teaching Points

- Emergency operation is a temporary measure—it runs at a fixed setpoint that may not match the customer's preference
- The emergency switch is useful for technicians during commissioning to verify basic heating/cooling without needing the remote
- Some manufacturers require multiple presses to cycle through modes—consult the installation manual

LAB 16.4

Perform a Preventive Maintenance Inspection

25–30 min | Proficiency | 40-Hour Pathway

Learning Objectives

Upon completion, the student will be able to:

1. Inspect and clean the indoor unit air filter
2. Inspect the outdoor unit coil and fan for obstructions
3. Check condensate drain line for blockage
4. Inspect refrigerant line insulation for damage

📋 Skill-Specific Materials

- Basic hand tools (screwdriver set)
- Clean rag
- Soft brush or vacuum with brush attachment

📖 Lesson Procedure

📝 Background

Regular maintenance is essential for mini-split performance and longevity. The most important maintenance items are: indoor filter cleaning (frequency varies based on usage and indoor air quality), outdoor coil inspection (seasonal), condensate drain verification (seasonal), and refrigerant line insulation check (annual). This skill teaches a systematic maintenance inspection.

🛠 Setup

1. System shut down and lockout/tagout applied
2. Gather cleaning supplies and inspection tools

📋 Procedure

1. Indoor filter: Open the indoor unit front panel. Remove the air filter(s). Inspect for dust and debris accumulation. Clean with water or vacuum. Allow to dry completely before reinstalling. Note: never operate the system without the filter installed.
2. Indoor unit coil: With the filter removed, visually inspect the evaporator coil for dust buildup, mold, or ice residue. If cleaning is needed, use manufacturer-approved coil cleaner.
3. Condensate drain: Locate the drain pan and drain line. Verify the line is not blocked by pouring a small amount of water into the drain pan and confirming it flows freely. Check for algae or mold growth in the pan. If unit has a condensate pump, power may have to be on before testing drain line.
4. Outdoor unit coil and fan: Inspect the condenser coil for debris (leaves, grass, dirt). Inspect the fan blades for damage. Clear any obstructions from around the unit (maintain minimum clearance per manufacturer specs). Verify power is still off before clearing any obstructions.
5. Refrigerant line insulation: Inspect the insulation on both liquid and vapor lines for cracks, gaps, or UV degradation. Damaged insulation reduces efficiency and can cause condensation.

🏁 Closure

- Discuss recommended maintenance intervals for each item
- Emphasize that filter cleaning is the single most impactful maintenance task—and the one most often neglected by homeowners

✅ Assessment

- Correct filter removal, inspection, cleaning, and reinstallation
- Systematic inspection of all maintenance items
- Ability to identify common maintenance issues

💡 Key Teaching Points

- A dirty indoor filter is the #1 cause of mini-split performance complaints and ice buildup
- Outdoor unit clearance requirements vary by manufacturer—typically 12–24 inches on all sides
- Condensate drain blockage can cause water damage in the occupied space—always verify drain flow during maintenance

LAB 17

Mini-Split System Recovery and Charging

40-Hour Pathway

This lab covers refrigerant handling procedures specific to mini-split systems: assessing charge by the superheat method, recovering refrigerant, and charging using the weigh-in method with both recovered and virgin refrigerant. EPA 608 certification (with A2L endorsement for R-454B systems) is required for all refrigerant handling activities.

⚠️ A2L Refrigerant Awareness

- All refrigerant handling procedures in this lab apply to both R-410A and A2L refrigerants (R-454B). When working with A2L refrigerants, additional precautions include: use of A2L-rated recovery equipment, leak detection with A2L-compatible sensors, ventilation requirements per manufacturer specifications, and awareness of mild flammability classification.
- Students must hold EPA 608 certification with A2L endorsement before handling R-454B refrigerant.

> **❄️ Cold Climate Consideration**
>
> Charging in cold ambient can require operating the system in emergency/test cooling mode to create measurable conditions.

🔄 Equipment Flexibility

- Commercial trainers: Use provided equipment documentation; labeling typically matches manufacturer materials.
- Field equipment: Use installation/service manual documentation. Create supplemental labels as needed for student orientation.
- Component kits: Individual components can be bench-mounted for isolated practice using generic diagrams.

LAB 17.1

Use the Superheat Method to Assess Charge

20–30 min | Proficiency | 40-Hour Pathway

🎯 Learning Objectives

Upon completion, the student will be able to:

1. Connect a gauge manifold to a mini-split system service port
2. Measure suction pressure and vapor line temperature
3. Calculate superheat and compare to manufacturer specifications

📋 Skill-Specific Materials

- Gauge manifold with hoses
- Pipe-clamp temperature probe
- P-T chart for system refrigerant
- Manufacturer's charging chart or superheat specifications

📖 Lesson Procedure

📝 Background

Mini-split systems are factory-charged for a specific line length. When line lengths are modified or refrigerant is lost, charge must be verified. The superheat method is a primary field technique: measure suction pressure (to determine evaporating temperature from the P-T chart) and vapor line temperature, then calculate superheat (vapor line temp minus evaporating temp). Compare to the manufacturer's specified range.

🛠️ Setup

1. System running in cooling mode for at least 10 minutes to stabilize
2. Connect gauge manifold to the low-side (suction) service valve on the outdoor unit
3. Attach pipe-clamp probe to the vapor line near the outdoor unit

📋 Procedure

1. Record the suction (low-side) pressure from the gauge manifold.
2. Look up the corresponding evaporating temperature from the P-T chart for the system's refrigerant.
3. Record the vapor line temperature from the pipe-clamp probe.
4. Calculate superheat: Vapor line temperature minus evaporating temperature.
5. Compare the calculated superheat to the manufacturer's specification.
6. If superheat is too high, the system may be undercharged. If too low, the system may be overcharged or have an EEV issue.

Closure

- Review calculations as a class
- Discuss how mini-split superheat targets differ from ducted systems (sometimes lower due to EEV precision)
- Emphasize that superheat is measured at the suction line near the outdoor unit, not at the indoor unit. Make sure students understand to check manual for precise location.

Assessment

- Correct gauge manifold connection
- Accurate pressure and temperature readings
- Correct superheat calculation and comparison to manufacturer spec

Key Teaching Points

- Mini-split systems use EEVs that maintain tighter superheat control than TXVs—expect lower and more consistent superheat values
- Always refer to the manufacturer's charging chart—generic superheat targets may not apply to inverter-driven systems
- Suction pressure on a mini-split varies with compressor speed—ensure the system is at steady-state before reading

LAB 17.2

Recover Refrigerant from a Mini-Split System

20–30 min | Proficiency | 40-Hour Pathway | A2L Consideration

Learning Objectives

Upon completion, the student will be able to:

1. Connect recovery equipment to a mini-split system
2. Perform a liquid and vapor recovery to the EPA-required termination pressure
3. Weigh and record the amount of refrigerant recovered

📋 Skill-Specific Materials

- EPA-certified recovery machine
- Empty recovery tank (on scale)
- Gauge manifold with hoses
- Inline filter drier
- Scale
- Schrader core removal tools

📖 Lesson Procedure

📝 Background

Refrigerant recovery is required by EPA regulation before opening any part of the refrigerant circuit. Mini-split recovery connects to the service valves on the outdoor unit. Recovery must continue until the system reaches 0 psig for systems under 200 lbs of refrigerant (EPA requirement for high-pressure systems). Always recover into a properly rated and labeled recovery tank.

🛠️ Setup

1. System shut down and de-energized
2. Recovery equipment assembled: recovery machine, two extra hoses, inline filter drier, recovery tank on scale, two Schrader removal tools
3. Record the initial weight of the recovery tank

📋 Procedure

1. Remove Schrader valve cores from service ports to maximize refrigerant flow during recovery.
2. Install an inline filter drier between the system and the recovery machine to protect the machine from contaminants.
3. Connect the gauge manifold: system service valves to the low and high side of the manifold; manifold center hose to the filter drier inlet; connect an extra hose from the filter drier outlet to the recovery machine inlet. Use the second extra hose to connect the recovery machine outlet to the vapor side of the recovery tank.
4. Open valves and start the recovery machine. Begin with liquid recovery (if system has liquid available), then switch to vapor recovery.
5. Monitor the recovery tank weight and gauge pressures. Continue recovery until the system reaches 0 psig (EPA requirement for high-pressure systems under 200 lbs).
6. Close valves, shut off recovery machine. Record the final weight of the recovery tank and calculate the amount recovered.
7. Reinstall Schrader valve cores. Cap all service ports.

🏁 Closure

- Review the EPA termination pressure requirement: 0 psig for high-pressure systems under 200 lbs
- Discuss the importance of the inline filter drier for protecting the recovery machine
- Review proper recovery tank labeling and handling

✅ Assessment

- Correct connection of recovery equipment
- Recovery to EPA-required termination pressure (0 psig)
- Accurate weight documentation of recovered refrigerant

💡 Key Teaching Points

- EPA requires recovery to 0 psig for high-pressure systems under 200 lbs—not 5 psig as some older references state
- Removing Schrader cores speeds recovery significantly on mini-split systems with small-diameter service ports
- Always use an inline filter drier—contaminants from a failed compressor can damage the recovery machine

⚠️ **A2L Refrigerant Awareness**

When recovering A2L refrigerants (R-454B), use recovery equipment rated for A2L/mildly flammable refrigerants.

Ensure adequate ventilation during recovery—A2L refrigerants have a mild flammability classification.

Use A2L-compatible leak detection equipment to verify no leaks at connections before and after recovery.

LAB 17.3

Charge a Mini-Split System with Recovered Refrigerant (Weigh-In)

20–30 min | Proficiency | 40-Hour Pathway

🎯 Learning Objectives

Upon completion, the student will be able to:

1. Calculate the correct charge amount from the manufacturer's nameplate and line length specifications
2. Set up the weigh-in charging equipment
3. Charge the system to the correct weight using recovered refrigerant

📋 Skill-Specific Materials

- Recovery tank with clean recovered refrigerant (same type as system)
- Gauge manifold
- Scale (accurate to 0.1 oz)
- Manufacturer's nameplate data and install manual (factory charge and per-foot adjustment)

📖 Lesson Procedure

📝 Background

Mini-split systems are charged by weight (weigh-in method) rather than by superheat or subcooling adjustment. The correct charge is calculated from the manufacturer's nameplate: factory charge plus or minus an adjustment for actual line length vs. factory line length.

🛠️ Setup

1. System evacuated to proper vacuum level (500 microns or below)
2. Refrigerant tank on scale with known weight of available refrigerant
3. Calculate target charge weight from manufacturer's nameplate

📋 Procedure

1. Calculate the target charge: Factory charge (from nameplate) + (actual line length minus factory line length) × per-foot adjustment factor.
2. Connect the recovery tank (liquid valve) to the gauge manifold. Connect the manifold to the system liquid line service valve.
3. Zero the scale with the recovery tank connected.
4. Open valves and allow liquid refrigerant to flow into the system. Monitor the scale—stop when the target weight has been transferred.
5. Close valves. Start the system and allow it to stabilize. Verify superheat and subcooling are within the manufacturer's range.

🏁 Closure

- Review the charge calculation and emphasize the line length adjustment
- Discuss why weigh-in is the primary charging method for mini-splits (EEV systems cannot be charged by superheat/subcooling alone)

✅ Assessment

- Correct charge weight calculation including line length adjustment
- Accurate charging to target weight
- Verification of superheat after charging

LAB 17.4

Charge a Mini-Split System with Virgin Refrigerant

20–30 min | Proficiency | 40-Hour Pathway

🎯 Learning Objectives

Upon completion, the student will be able to:

1. Charge a mini-split system using virgin refrigerant from a new cylinder
2. Verify charge correctness using the superheat method

📋 Skill-Specific Materials

- Virgin refrigerant cylinder (correct type for system)
- Gauge manifold
- Scale
- Pipe-clamp temperature probe

📖 Lesson Procedure

📝 Background

Charging with virgin (new) refrigerant follows the same weigh-in procedure as recovered refrigerant. The key difference is the source: a new, sealed cylinder vs. a recovery tank. Virgin refrigerant is used for initial commissioning, after a major repair, or when recovered refrigerant is insufficient or contaminated.

🛠 Setup

1. System evacuated to proper vacuum level
2. Virgin refrigerant cylinder on scale
3. Calculate target charge weight

📋 Procedure

1. Calculate target charge using the same method as Lab 17.3.
2. Connect the virgin refrigerant cylinder (in liquid position) to the gauge manifold and system liquid line service valve.
3. Zero the scale and charge to target weight.
4. Start the system. Allow to stabilize (10+ minutes in cooling mode). Measure and verify superheat against manufacturer's specification.

🏁 Closure

- Compare the experience of charging from a recovery tank vs. a virgin cylinder
- Emphasize that the procedure is identical—only the refrigerant source changes

Assessment

- Correct charge calculation and accurate charging
- Successful superheat verification
- Proper handling of virgin refrigerant cylinder

LAB 18

Mini-Split Pressure and Temperature Measurements

40-Hour Pathway

This lab covers advanced pressure and temperature measurement techniques for mini-split systems, including pump-down procedures, thermocouple probe measurements, and the total superheat method for system performance verification.

🔄 Equipment Flexibility

- Commercial trainers: Use provided equipment documentation; labeling typically matches manufacturer materials.
- Field equipment: Use installation/service manual documentation. Create supplemental labels as needed for student orientation.
- Component kits: Individual components can be bench-mounted for isolated practice using generic diagrams.

LAB 18.1

Pump Down a Mini-Split Heat Pump

35–45 min | Proficiency | 40-Hour Pathway

🎯 Learning Objectives

Upon completion, the student will be able to:

1. Explain the purpose and procedure for pumping down a mini-split system
2. Perform a pump-down using the service valves on the outdoor unit
3. Verify pump-down completion using gauge manifold readings

📋 Skill-Specific Materials

- Gauge manifold with hoses
- Allen wrench set (for service valve stems)
- Adjustable wrenches

📖 Lesson Procedure

📝 Background

Pumping down a mini-split system stores the refrigerant charge in the outdoor unit by closing the liquid line service valve while the compressor continues running. This allows the indoor unit or refrigerant lines to be opened for repair without losing the charge. The procedure requires monitoring suction pressure—when it drops to near 0 psig, the vapor valve is closed and the system is shut down.

🛠️ Setup

1. System operating in cooling mode
2. Gauge manifold connected to suction (low-side) service port
3. Allen wrench sized for the service valve stems

📋 Procedure

1. With the system running in cooling mode, close the liquid line service valve (turn the valve stem clockwise with the Allen wrench). This stops liquid refrigerant from flowing to the indoor unit.
2. Monitor the suction pressure on the gauge manifold. As the compressor continues running, it pumps refrigerant from the indoor unit and lines back into the outdoor unit.
3. When suction pressure drops to approximately 0–2 psig, close the vapor line (suction) service valve.
4. Immediately shut off the system using the thermostat or disconnect. Do not allow the compressor to run in a vacuum.
5. Verify: both service valves closed, suction pressure stable at 0–2 psig. The charge is now stored in the outdoor unit.
6. The indoor unit and refrigerant lines can now be opened for service without refrigerant loss.

🏁 Closure

- Discuss when pump-down is used: line repairs, indoor unit replacement, relocating the indoor unit
- Emphasize the critical timing: close the vapor valve and shut down before the compressor pulls into vacuum
- Discuss the reverse procedure: opening valves to restore operation after service is complete

✅ Assessment

- Correct pump-down procedure and timing
- Suction pressure monitoring throughout the process
- Understanding of when and why pump-down is used

💡 Key Teaching Points

- Never allow the compressor to run in a vacuum—this can damage the compressor and draw moisture into the system
- Pump-down preserves the entire charge in the outdoor unit—no refrigerant is lost or recovered
- After service, open the liquid valve first, then the vapor valve, to restore normal operation

> **❄️ Cold Climate Consideration**
>
> In cold weather, pump-down may be less efficient because the compressor's capacity is reduced at low ambient temperatures.
> If the system will be shut down for an extended period in freezing weather, ensure all condensate is drained from the indoor unit to prevent freeze damage.

LAB 18.2

Measure Vapor and Liquid Line Temperatures

30–40 min | Proficiency | 40-Hour Pathway

🎯 Learning Objectives

Upon completion, the student will be able to:

1. Properly attach thermocouple probes to refrigerant lines for accurate temperature measurement
2. Measure vapor line and liquid line temperatures in both cooling and heating modes
3. Calculate superheat and subcooling from measured temperatures and pressures

📋 Skill-Specific Materials

- Pipe-clamp thermocouple probes (2)
- Digital thermometer with dual probe inputs
- Gauge manifold
- P-T chart
- Insulation tape or foam for probe insulation

📖 Lesson Procedure

📝 Background

Accurate temperature measurement on refrigerant lines requires proper probe placement and insulation. The pipe-clamp probe must make full contact with the pipe surface, and the probe and surrounding pipe should be insulated from ambient air to prevent false readings. This skill teaches proper technique for both vapor and liquid line measurements.

🛠️ Setup

1. System running in cooling mode for 10+ minutes
2. Gauge manifold connected
3. Two pipe-clamp probes available

📋 Procedure

1. Attach the first pipe-clamp probe to the vapor (suction) line near the outdoor unit. Ensure full contact with the pipe surface. Insulate the probe and adjacent pipe section with insulation tape or foam.
2. Attach the second probe to the liquid line near the outdoor unit. Same technique: full contact, insulated.
3. Record both temperatures. Record gauge pressures. Calculate superheat and subcooling.
4. Switch the system to heating mode. Allow 10 minutes to stabilize.
5. Note that in heating mode, the line roles reverse: the vapor line from the indoor unit is now the suction line, and the liquid line from the indoor unit is now the high-pressure liquid line. Measure and record temperatures and pressures in heating mode. Calculate superheat and subcooling.

🏁 Closure

- Compare cooling vs. heating measurements—discuss how the line roles reverse
- Emphasize the importance of probe insulation for accurate readings
- Discuss common errors: probe not fully in contact, ambient air affecting the reading

✅ Assessment

- Correct probe placement and insulation technique
- Accurate temperature readings in both modes
- Correct superheat and subcooling calculations for both modes

💡 Key Teaching Points

- Probe insulation is critical—an uninsulated probe can read 5–10°F off the actual pipe temperature
- In heating mode, the "suction line" is the line returning from the outdoor coil—not the same physical line as in cooling mode
- Always take readings at the outdoor unit service valves for the most accurate measurements

LAB 18.3

Use Total Superheat to Evaluate System Performance

25–30 min | Proficiency | 40-Hour Pathway

🎯 Learning Objectives

Upon completion, the student will be able to:

1. Explain the total superheat method and when it is used
2. Measure all required parameters for the total superheat calculation
3. Compare measured total superheat to the manufacturer's target chart

📋 Skill-Specific Materials

- Gauge manifold
- Pipe-clamp temperature probes
- Digital thermometer
- Wet-bulb thermometer or psychrometer
- Manufacturer's total superheat charging chart

📖 Lesson Procedure

📝 Background

The total superheat method evaluates system performance by comparing measured superheat to a target value derived from outdoor ambient temperature and indoor wet-bulb temperature. This method is primarily used for systems with fixed metering devices, but can verify mini-split performance as a secondary check after weigh-in charging. The target superheat accounts for environmental conditions, making it more accurate than a single fixed target.

🛠️ Setup

1. System running in cooling mode for 15+ minutes at steady state
2. Gauge manifold connected
3. Pipe-clamp probe on suction line
4. Wet-bulb thermometer measuring indoor return air temperature

📋 Procedure

1. Measure outdoor ambient (dry-bulb) temperature.
2. Measure indoor return air wet-bulb temperature using the psychrometer or wet-bulb thermometer.
3. Measure suction pressure and vapor line temperature. Calculate actual superheat.
4. Using the manufacturer's total superheat chart, locate the intersection of outdoor ambient temperature and indoor wet-bulb temperature. Read the target superheat.
5. Compare actual superheat to target. If actual is within ±5°F of target, the system charge is acceptable.

🏁 Closure

- Discuss when the total superheat method is most useful vs. when the weigh-in method takes precedence
- Review how outdoor and indoor conditions affect the target superheat

✅ Assessment

- Correct measurement of all required parameters
- Accurate use of the total superheat chart
- Correct comparison and interpretation of results

💡 Key Teaching Points

- The total superheat method is a verification tool for mini-splits—not a primary charging method (weigh-in is primary)
- Wet-bulb temperature accounts for humidity—a humid day requires different superheat than a dry day at the same temperature
- If the total superheat check disagrees with the weigh-in charge, investigate for leaks or restrictions before adjusting charge

LAB 19

Mini-Split Heat Pump Component Tests

40-Hour Pathway | Instructor-Led Demonstration | Extended Practice

This lab covers diagnostic testing procedures for mini-split-specific components. Mini-split diagnostics differ from ducted systems: inverter-driven compressors, electronic expansion valves (EEVs), multiple thermistors, DC fan motors, and proprietary communication protocols. Each skill focuses on manually reproducible fault scenarios.

⚙️ Required Components/Systems

Residential mini-split heat pump system (operational) with accessible indoor and outdoor units, inverter board, service valves, and component access panels.

🔧 Required Diagnostic Tools

- Digital multimeter (AC/DC voltage, resistance)
- Clamp-on ammeter
- Pipe-clamp temperature probe and digital thermometer
- Gauge manifold (for pressure observation during refrigerant-side tests)
- Manufacturer's error code reference chart
- Manufacturer's thermistor temperature-resistance chart
- Troubleshooting Process Recording Charts

🦺 Required PPE

Safety glasses, gloves, non-melting and non-flammable fabrics, and work boots. Electrical meters available to confirm power is off when required. Main power switch enclosure locked when not in use.

🔄 Equipment Flexibility

- Commercial trainers: Use provided diagnostic panel test points per manufacturer documentation. After completing each measurement, also have students locate the same test point on the actual component.
- Field equipment: Follow the component access guidance in each skill's Background section. Use installation/service manual documentation; create supplemental labels as needed.
- Component kits: Individual components can be bench-mounted for isolated testing practice using generic diagrams.

Instructor Notes

- Mini-split diagnostics rely heavily on manufacturer error codes displayed on the indoor unit. Obtain the error code chart for your specific equipment before beginning.
- Mini-split compressors are inverter-driven (variable speed)—standard capacitor and winding tests differ from single-speed compressors.
- Label all accessible components before student access, especially the inverter board, thermistor connections, EEV motor, and communication wiring.

Extended Practice

- Programs with fault insertion software or hardware can extend these skills with additional scenarios that are not practical to create manually, including: inverter board failure simulation, EEV stepper motor malfunction, multi-sensor faults, and communication protocol diagnostics.
- The troubleshooting tables and discussion items provided with each skill cover the diagnostic logic for these additional faults.

LAB 19.1

Test a Compressor and Inverter Control

40–50 min | Proficiency | Instructor-Led Demo / Extended Practice

Learning Objectives

Upon completion, the student will be able to:

1. Identify the inverter-driven compressor electrical connections
2. Measure compressor winding resistance (U, V, W phases)
3. Interpret inverter board error codes related to compressor faults

Lesson Procedure

Background

Mini-split compressors are three-phase inverter-driven motors, even when powered by single-phase supply. The inverter board converts single-phase AC to variable-frequency three-phase AC. Compressor terminals are labeled U, V, and W (rather than C, S, R). Winding resistance should be equal across all three phases.

On field equipment, compressor terminals are accessed inside the outdoor unit. The inverter board connects to the compressor through three power wires (U, V, W). Disconnect these wires before measuring winding resistance.

🛠️ Setup

1. System de-energized and locked out
2. Outdoor unit access panels removed

📋 Procedure

1. This skill combines hands-on measurement practice with discussion of inverter-specific faults.
2. De-energize the system. Disconnect the U, V, W wires from the compressor terminals (or from the inverter board output).
3. Measure resistance: U–V, V–W, U–W. All three readings should be equal (±0.5 Ω). Record all three values.
4. Measure from each terminal to the compressor case/ground. All should read OL. Any reading indicates a ground fault.
5. Reconnect U, V, W wires. Restore power and start the system. Observe for error codes on the indoor unit display.

📐 Measurement Interpretation Reference

Measurement	Expected Normal	Indicates Fault
U–V resistance	Equal to V–W and U–W (manufacturer spec)	Unequal readings = phase imbalance, replace compressor
V–W resistance	Same as U–V	OL on any phase = open winding
U–W resistance	Same as U–V	Near 0 on any phase = shorted winding
Any phase to ground	OL	Any reading = ground fault, replace compressor

🏁 Closure

- Discuss how three-phase winding tests differ from single-phase (equal resistance vs. unequal C–S/C–R)
- Review the error code chart for compressor-related codes

✅ Assessment

- Correct three-phase winding resistance measurement
- Ground fault test on all phases
- Understanding of inverter compressor vs. single-speed compressor diagnostics

💡 Key Teaching Points

- Inverter compressor windings are three-phase (U, V, W) with equal resistance across all pairs
- The inverter board is a common cause of mini-split compressor failure symptoms—always check the board before condemning the compressor
- Error codes on the indoor unit display are the first-line diagnostic for mini-split systems

> **❄️ Cold Climate Consideration**
>
> Cold climate mini-split compressors are designed for higher compression ratios—winding resistance specifications may differ from standard models.
> Inverter boards in cold climate systems work harder at low ambient temperatures—premature board failure can be caused by voltage fluctuations during winter storms.

LAB 19.2

Test a Linear Expansion Valve (LEV)

30–40 min | Proficiency | Instructor-Led Demo / Extended Practice

🎯 Learning Objectives

Upon completion, the student will be able to:

1. Identify the LEV and its stepper motor connections
2. Diagnose a restriction using pressure-temperature analysis
3. Interpret error codes related to LEV faults

📋 Skill-Specific Materials

- P-T chart for system refrigerant

📖 Lesson Procedure

📝 Background

Terminology note: LEV (Linear Expansion Valve) and EEV (Electronic Expansion Valve) are essentially the same functional component — an electronically controlled, high-precision metering device for HVAC systems. LEVs are often a specific type of EEV, using a geared stepper motor to move a pin linearly, while EEV is the general term for all electronic metering devices.

The LEV is controlled by the inverter board via a stepper motor. Unlike a TXV, the LEV can fail in ways that produce error codes rather than just pressure symptoms. Common LEV faults include: valve stuck closed (restriction), valve stuck open (flooding), or stepper motor failure (no response to board commands).

🛠️ Setup

1. System running in cooling mode for 10+ minutes
2. Gauge manifold connected; pipe-clamp probe on suction line

⚠️ Fault Scenarios

> Fault Scenario: Refrigerant Restriction (Ball Valve)
> Insert: Partially close the liquid line ball valve (50–75% closed). This simulates an LEV stuck partially closed.
> Symptoms: Low suction pressure. High superheat. Frost may form near the restriction point. Supply air temperature rises.
> Key Measurement: Superheat significantly above manufacturer's target. Low-side pressure below normal operating range.
> Diagnosis: ____
> Reset: Open ball valve fully. Allow 10 minutes to restabilize.

🏁 Closure

- Discuss how LEV faults differ from TXV faults: LEVs generate error codes, TXVs only show pressure symptoms
- Review the error code chart for LEV-related codes

✅ Assessment

- Correct identification of LEV restriction symptoms
- Understanding of how LEV diagnostics differ from TXV diagnostics

LAB 19.3

Test Thermistors (Including Defrost)

30–40 min | Proficiency | Instructor-Led Demo / Extended Practice

Learning Objectives

Upon completion, the student will be able to:

1. Identify the locations and functions of thermistors in a mini-split system
2. Measure thermistor resistance and compare to the temperature-resistance chart
3. Interpret error codes related to thermistor faults

Skill-Specific Materials

- Manufacturer's thermistor temperature-resistance chart
- Resistors for substitution (100 Ω and 100K Ω)

Lesson Procedure

Background

Mini-split systems use multiple thermistors (typically 4–8) for system control: room temperature, indoor coil, outdoor coil, outdoor ambient, suction line, discharge line, and others. Each thermistor reports to the inverter board, which uses the data to control compressor speed, EEV position, fan speed, and defrost timing. A failed thermistor produces an error code and may cause the system to shut down or operate in a degraded mode.

Setup

1. System de-energized for resistance measurements
2. Distribute thermistor temperature-resistance chart and error code chart

Procedure

1. Practice: with the system de-energized, disconnect each accessible thermistor in turn. Measure its resistance and compare to the temperature-resistance chart at the current ambient temperature. Record all readings.

Closure

- Review how mini-splits use many more thermistors than ducted systems
- Discuss the error code system as the primary diagnostic tool for sensor faults

Assessment

- Correct thermistor resistance measurement and chart comparison
- Correct interpretation of error codes for sensor faults

LAB 19.4

Test a Reversing Valve

25–35 min | Proficiency | Instructor-Led Demo / Extended Practice

Learning Objectives

Upon completion, the student will be able to:

1. Perform the touch test on a mini-split reversing valve
2. Test solenoid coil voltage and magnetism

Skill-Specific Materials

- Wrench for solenoid retaining screw

Lesson Procedure

Background

The reversing valve in a mini-split system operates identically to a ducted system. The diagnostic approach is the same as Lab 12.4: touch test, voltage check, magnetism test. The key difference is that the reversing valve on a mini-split may be harder to access due to the compact outdoor unit design.

Setup

1. System running in cooling mode with outdoor unit access panels removed

Closure

- Note that the diagnostic approach is identical to Lab 12.4—the same techniques apply to any reversing valve

Assessment

- Correct touch test, voltage check, and magnetism test

LAB 19.5

Test Indoor and Outdoor Fan Motors

30–40 min | Proficiency | Instructor-Led Demo / Extended Practice

Learning Objectives

Upon completion, the student will be able to:

1. Identify the DC fan motors used in mini-split indoor and outdoor units
2. Measure fan motor resistance and voltage
3. Interpret error codes related to fan faults

Skill-Specific Materials

- Manufacturer's fan motor specifications

Lesson Procedure

Background

Mini-split systems typically use DC brushless fan motors (not PSC motors with capacitors). These motors are controlled by the inverter board and do not have separate run capacitors. Fan faults produce error codes. Diagnostic approach: check for error codes, verify power supply to the motor, measure motor winding resistance.

Setup

1. System de-energized for resistance measurements

Procedure

1. Indoor fan: Locate the indoor fan motor connector on the indoor unit control board. Disconnect the motor connector. Measure resistance across the motor winding pins (per manufacturer specification). Record readings.
2. Outdoor fan: Locate the outdoor fan motor connector on the inverter board. Disconnect and measure resistance. Record.
3. Reconnect all connectors. Restore power. Start the system and observe for fan-related error codes.

Closure

- Discuss how DC brushless fan diagnostics differ from PSC fan diagnostics: no capacitor to test, board-controlled speed
- Review error codes for fan faults

Assessment

- Correct fan motor resistance measurement
- Understanding of DC fan motor vs. PSC motor diagnostics

LAB 20

Troubleshooting Residential Mini-Split Heat Pump Systems

40-Hour Pathway | Instructor-Led Demonstration | Extended Practice

This lab covers system-level troubleshooting for mini-split heat pump systems. Mini-split troubleshooting relies heavily on LED indicators and error codes displayed on the indoor unit. Each skill focuses on a different category of system fault.

⚙️ Required Components/Systems

Residential mini-split heat pump system (operational) with accessible indoor and outdoor units and manufacturer's error code documentation.

🔧 Required Diagnostic Tools

- Digital multimeter (AC/DC voltage, resistance)
- Clamp-on ammeter
- Manufacturer's error code chart and LED indicator guide
- Troubleshooting Process Recording Charts

🦺 Required PPE

Safety glasses, gloves, non-melting and non-flammable fabrics, and work boots. Electrical meters available to confirm power is off when required. Main power switch enclosure locked when not in use.

> ❄️ **Cold Climate Consideration**
>
> Communication faults between indoor and outdoor units are common in cold climates.

Equipment Flexibility

- Commercial trainers: Use provided diagnostic panel test points per manufacturer documentation. After completing each measurement, also have students locate the same test point on the actual component.
- Field equipment: Follow the component access guidance in each skill's Background section. Use installation/service manual documentation; create supplemental labels as needed.
- Component kits: Individual components can be bench-mounted for isolated testing practice using generic diagrams.

Extended Practice

- Programs with fault insertion software or hardware can extend these skills with additional scenarios that are not practical to create manually, including: software-generated inverter faults, multi-sensor failures, and communication protocol diagnostics.
- The troubleshooting tables and discussion items provided with each skill cover the diagnostic logic for these additional faults.

LAB 20.1

Use LED Indicators to Troubleshoot a Mini-Split System

35–45 min | Proficiency | Instructor-Led Demo / Extended Practice

Learning Objectives

Upon completion, the student will be able to:

1. Locate and read LED indicators on both indoor and outdoor units
2. Interpret common error codes using manufacturer documentation
3. Differentiate between communication errors, sensor errors, and component errors

Skill-Specific Materials

- Manufacturer's LED indicator and error code reference chart
- Resistors for thermistor substitution

📖 Lesson Procedure

📝 Background

Mini-split systems communicate faults through LED indicators on the indoor unit (visible to the occupant) and sometimes on the outdoor unit control board (visible to the technician). Error codes may appear as flashing patterns (number of flashes = error code), alphanumeric codes on a display, or combinations of LED colors. The manufacturer's error code chart is essential—codes are not standardized across brands.

🛠️ Setup

1. System operational
2. Distribute manufacturer's error code chart

⚠️ Fault Scenarios

> Fault Scenario A: Thermistor Error Code
> Insert: De-energize. Disconnect one indoor thermistor. Re-energize.
> Symptoms: Indoor unit displays a specific error code for the disconnected sensor. System may enter degraded mode or shut down.
> Key Measurement: Read the error code from the indoor unit display. Look up the code in the manufacturer's chart. Code identifies the specific sensor.
> Diagnosis: ____
> Reset: De-energize. Reconnect thermistor. Re-energize. Clear error per manufacturer procedure.

> Fault Scenario B: Power Supply Error
> Insert: Trip the outdoor unit disconnect briefly, then restore. Some systems will display a power error code after an unclean power cycle.
> Symptoms: Indoor unit may display a power-related error code. System may require a reset procedure.
> Key Measurement: Read error code. Verify incoming voltage at the outdoor unit disconnect. If voltage is correct, the error was caused by the power interruption.
> Diagnosis: ____
> Reset: Clear error per manufacturer procedure (may require power cycle or remote button sequence).

Closure

- Review the categories of error codes: sensor errors, communication errors, component errors, power errors
- Emphasize that the error code chart is the technician's most important tool for mini-split troubleshooting

Assessment

- Correct reading of LED indicators
- Correct error code lookup and interpretation
- Understanding of error code categories

Key Teaching Points

- Error codes are not standardized across manufacturers—always use the correct manufacturer's chart
- The indoor unit display is the primary diagnostic interface—check it before opening any panels
- Some error codes require a specific reset procedure—simply power-cycling may not clear the code

LAB 20.2

Troubleshoot a Non-Running Outdoor Unit

35–45 min | Proficiency | Instructor-Led Demo / Extended Practice

Learning Objectives

Upon completion, the student will be able to:

1. Diagnose a non-running outdoor unit by checking power supply, error codes, and component status
2. Verify incoming voltage at the outdoor unit disconnect and control board

Lesson Procedure

Background

A non-running outdoor unit can be caused by: no power (tripped breaker, blown fuse, disconnected wiring), control board fault, compressor lockout, or communication failure between indoor and outdoor units. The diagnostic approach starts with verifying power, then checking for error codes, then testing individual components.

⚠️ Fault Scenarios

> Fault Scenario A: Outdoor Unit Disconnect Tripped
> Insert: Turn off the outdoor unit disconnect.
> Symptoms: Indoor unit runs (fan operates). Outdoor unit is completely off—no compressor, no fan. Indoor unit may eventually display a communication error code.
> Key Measurement: Check voltage at outdoor unit disconnect: 0 V. Confirm indoor unit has power. Disconnect is off or breaker tripped.
> Diagnosis: ____
> Reset: Restore disconnect. Immediate.

> Fault Scenario B: Communication Wire Disconnected
> Insert: De-energize. Disconnect the communication cable between indoor and outdoor units at the outdoor unit terminal block. Re-energize.
> Symptoms: Both units have power. Indoor unit displays a communication error code. Outdoor unit does not respond to indoor unit commands.
> Key Measurement: Error code indicates communication fault. Verify voltage at communication terminals. Check physical connection of communication cable.
> Diagnosis: ____
> Reset: De-energize. Reconnect communication cable. Re-energize.

🏁 Closure

- Discuss the diagnostic hierarchy: power first, then communication, then components
- Review communication error codes and their meaning

✅ Assessment

- Correct power verification procedure
- Correct identification of communication fault via error code

💡 Key Teaching Points

- Always verify power first—a non-running outdoor unit is most commonly a power issue
- Communication errors are unique to mini-splits—ducted systems don't have this failure mode
- The communication cable carries low-voltage data signals—damage to this cable can cause intermittent faults that are hard to diagnose

LAB 20.3

Troubleshoot a Frequently Cycling Outdoor Unit

30–40 min | Proficiency | Instructor-Led Demo / Extended Practice

🎯 Learning Objectives

Upon completion, the student will be able to:

1. Identify frequent cycling patterns in a mini-split system
2. Diagnose cycling caused by a dirty filter or airflow restriction

📖 Lesson Procedure

📝 Background

Mini-split systems use inverter compressors that modulate speed rather than cycling on and off. Frequent cycling (compressor starting and stopping repeatedly) indicates a fault condition, not normal modulation. Causes include: high-pressure or low-pressure safety trips, thermistor faults causing erratic readings, dirty filters restricting airflow, or refrigerant charge issues.

⚠️ Fault Scenarios

> Fault Scenario: Dirty Filter Causing Cycling
> Insert: Install a severely dirty or restrictive filter in the indoor unit.
> Symptoms: System starts normally. After several minutes, indoor coil may begin to ice. System may shut down and restart. Error code may appear for coil temperature or high-pressure protection.
> Key Measurement: Check indoor filter—visibly dirty/restricted. Indoor coil temperature lower than normal. Error code for protection trip.
> Diagnosis: ____
> Reset: Remove dirty filter. Install clean filter or run without filter briefly to verify system stabilizes.

🏁 Closure

- Discuss how inverter compressors should modulate speed, not cycle on/off—cycling indicates a fault
- Emphasize that a dirty filter is the most common cause of mini-split cycling and icing

Assessment

- Ability to distinguish normal compressor modulation from abnormal cycling
- Correct identification of dirty filter as root cause

Key Teaching Points

- Inverter compressors should modulate, not cycle—on/off cycling means something is wrong
- A dirty indoor filter is a common cause of mini-split performance problems and error codes
- Always check the filter before proceeding to more complex diagnostics

LAB 20.4

Troubleshoot a Non-Running Indoor Unit

25–35 min | Proficiency | Instructor-Led Demo / Extended Practice

Learning Objectives

Upon completion, the student will be able to:

1. Diagnose a non-running indoor unit while the outdoor unit operates
2. Check indoor unit power supply and control board status

Lesson Procedure

Background

A non-running indoor unit with an operating outdoor unit indicates either an indoor unit power issue, a communication fault, or an indoor fan motor/control board failure. The indoor unit typically receives power from the outdoor unit through the interconnecting wiring.

⚠️ Fault Scenarios

> Fault Scenario: Indoor Unit Communication Disconnected
> Insert: De-energize. Disconnect the communication cable at the indoor unit terminal block. Re-energize.
> Symptoms: Outdoor unit runs (compressor and fan operate). Indoor unit is off—no fan, no display. Outdoor unit continues unaware that communication is broken.
> Key Measurement: No voltage or signals on communication cable. Indoor unit receives power but cannot communicate.
> Diagnosis: ____
> Reset: De-energize. Reconnect communication cable. Re-energize.

🏁 Closure

- Discuss that indoor unit power often comes through the outdoor unit—losing outdoor unit power can also disable the indoor unit

✅ Assessment

- Correct diagnostic approach for non-running indoor unit
- Understanding of indoor/outdoor unit power and communication relationship

LAB 20.5

Troubleshoot Communication Faults

30–40 min | Proficiency | Instructor-Led Demo / Extended Practice

🎯 Learning Objectives

Upon completion, the student will be able to:

1. Identify communication faults using error codes
2. Inspect and test the communication cable between indoor and outdoor units

📖 Lesson Procedure

1. Identify the communication cable between indoor and outdoor units. Note the wiring color codes and terminal designations on both ends.
2. Power the system and observe operation. Note any error code displayed on the indoor unit.
3. Look up the error code in the manufacturer's chart to determine whether the fault is a communication issue or a different fault category.
4. De-energize the system. Inspect the communication cable along its full length for damage, kinks, or improper routing (especially proximity to high-voltage wiring).
5. Check terminal connections at both indoor and outdoor units for looseness, corrosion, or backed-out wires.
6. If a fault is found, repair the cable or reseat the connection. Re-energize and verify the error code clears.

📝 Background

Mini-split indoor and outdoor units communicate via a dedicated communication cable (typically 2–3 wire). Communication faults are among the most common mini-split service issues, caused by damaged cables, loose connections, or electromagnetic interference from nearby power wiring. The error code identifies the fault; physical inspection locates the cause.

🛠️ Setup

1. System powered with both units accessible
2. Manufacturer's error code reference chart distributed

⚠️ Fault Scenarios

> Fault Scenario: Loose Communication Terminal
> Insert: De-energize. Back out (loosen) one of the communication terminal screws at the outdoor unit so the conductor is not making solid contact, but leave the wire in the terminal so the fault looks intact at a glance. Re-energize.
> Symptoms: Indoor unit may run briefly, then display a communication error code. Outdoor unit does not respond, or cycles unpredictably.
> Key Measurement: Read the error code from the indoor unit display and confirm it is a communication-related code. Wiggle test the suspect connection while monitoring; intermittent recovery confirms a loose terminal.
> Diagnosis: ____
> Reset: De-energize. Re-tighten the terminal. Re-energize and verify the error clears.

🏁 Closure

- Discuss that communication faults can be intermittent—they may not reproduce every time
- Review proper communication cable routing: separate from high-voltage wiring, protected from UV and physical damage

💡 Key Teaching Points

- Communication error codes typically indicate a cable, terminal, or interference problem — not a failed control board
- A wiggle test on suspect connections while watching the error code is one of the fastest ways to find an intermittent fault
- Always separate communication cables from high-voltage wiring to prevent electromagnetic interference
- Backed-out terminal screws are a very common installation defect — check both ends before condemning the cable

✅ Assessment

- Correct identification of communication fault via error code
- Systematic inspection of the communication cable and terminals at both units
- Correct repair (re-tightening or re-terminating the connection) and verification that the error clears