HIGH PERFORMANCE

HEAT PUMPS

CLIFTON BECK, CSME

DESIGN > INSTALLATION > COMMISSIONING

HVAC Excellence
esco institute

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Preface

Welcome to the High-Performance Heat Pump course! This course is specifically designed as an advanced supplement to the ESCO Institute's *Heat Pump Operation, Installation, and Service* curriculum. It is geared towards professionals who already possess foundational education and experience in heat pump systems and are looking to deepen their expertise in high-performance heat pump technology.

In this course, you will explore the latest advancements in heat pump technology, focusing on performance optimization, energy efficiency, as well as proper design and equipment selection. Our goal is to equip you with the knowledge and skills needed to work with the most sophisticated heat pump systems available today, ensuring you are prepared to meet the demands of modern HVAC environments.

By the end of this course, you will be able to confidently select the most appropriate heat pump system, providing superior efficiency and achieving the highest levels of comfort and reliability. Let's get started on advancing your career and enhancing your skill set with cutting-edge insights into high-performance heat pump technology!

If you currently hold a Heat Pump Service Certification from HVAC Excellence (or NATE), and obtained that certification before May 2023, successfully completing this course will qualify you for Energy-Skilled Recognition. Additionally, your company will be eligible for inclusion on the Department of Energy's (DOE) Energy-Skilled Recognized Contractors list.

For those who are not yet Heat Pump Service Certified, this course will serve as a supplemental course to the Heat Pump Operation, Installation and Service curriculum from ESCO. Together these courses will prepare you for the HVAC Excellence Heat Pump Service Certification exam. Passing this exam will also qualify you to be included on the DOE's Energy-Skilled Recognized Contractors list.

Introduction

In today's world, the push for energy efficiency and environmental sustainability has never been more urgent. One technology at the forefront of this movement is the heat pump. Opting for a heat pump offers dual benefits: enhancing home comfort and contributing to a healthier planet. Unlike traditional heating systems, heat pumps use less energy, emit fewer pollutants, and can integrate with renewable energy sources like solar and wind power. This makes them not only a smart choice for homeowners but also a crucial step toward a more sustainable future.

Choosing a heat pump is about more than just comfort; it’s about making a responsible choice for the environment. These systems significantly reduce energy consumption and greenhouse gas emissions while helping stabilize the energy grid by working with clean, renewable sources. In regions with cold winters and hot summers, heat pumps provide efficient heating and cooling year-round, further enhancing their appeal as a versatile solution for both residential and commercial buildings.

In addition to their environmental benefits, heat pumps are gaining widespread adoption due to their efficiency. In states like New York, installations surged 37% from 2021 to 2022, with over 29,500 heat pump projects completed in 2022 alone. Nationally, heat pump installations have outpaced gas furnaces, signaling a shift in the heating and cooling industry toward more sustainable, high-performance options.

This book is designed to guide you through the next generation of high-performance heat pumps. Whether you're a homeowner, technician, or educator, understanding the advantages of these systems and how to properly install and maintain them is key to keeping pace with modern HVAC innovations. As educators, it's essential to stay informed about the latest trends and technological advancements to prepare for the next wave of skilled professionals in the field.

Over the course of this book, we will explore various aspects of heat pumps, from their environmental impact to their role in energy diversification. By the end of this journey, you will not only have a deeper understanding of heat pumps but also be better equipped to make informed decisions or teach others about their growing importance in the world of sustainable energy.

Let's embark on this exploration of heat pumps and their potential to reshape the future of heating and cooling.

Definitions

Air-Conditioning, Heating, and Refrigeration Institute (AHRI) develops technical standards that are used worldwide for testing HVACR equipment. These standards ensure that products perform as advertised and meet regulatory requirements.

Balance point of a heat pump system is a critical concept in ensuring optimal heating performance. It is determined by the intersection of two key factors: the load line, which is calculated based on building-specific heating demands, and the heat pump's capacity.

Bus bars distribute electricity from the main breaker to the different circuits in the panel, ensuring power reaches all parts of the home.

Circuit breakers are designed to protect each individual circuit from being overloaded. If too much current flows through, the breaker will trip, cutting off the power to prevent damage.

Conduction is the direct transfer of heat through a material. If you touch a metal rod that's been heated on one end, you'll feel the heat traveling through the material.

Convection is the movement of heat through fluids, including both liquids and gases.

Coefficient of Performance (COP) is the ratio of useful heating or cooling output to the amount of energy consumed.

Displacement, commonly known as Partial Load, refers to HVAC systems that can adjust their output based on the current heating or cooling needs.

Ducted systems rely on a network of piping to distribute heated or cooled air throughout the building.

Ductless systems, such as mini-split heat pumps, operate without ducts and offer more flexibility in room-specific temperature control.

Electronic Expansion Valve (EEV) is an electrical metering device that operates similarly to a Thermostatic Expansion Valve (TEV/TXV) by modulating the flow of refrigerant according to the refrigerant suction temperature.

Heating Seasonal Performance Factor (HSPF) is the ratio of heating output to electricity consumption over a typical heating season.

Heating Seasonal Performance Factor 2 (HSPF2) is the ratio of heating output to electricity consumption over a typical heating season, based on new testing standards as of January 1, 2023.

International Energy Conservation Code (IECC) was introduced in 1998, and addresses energy efficiency on several fronts including cost savings, reduced energy usage, conservation of natural resources and the impact of energy usage on the environment.

Inverter board, also known as an inverter control, is a key component in converting power supply types. It starts by converting single-phase AC voltage into DC voltage using a process called rectification, facilitated by diodes.

Infrared (IR) refers to a type of electromagnetic radiation that falls between visible light and microwaves in the electromagnetic spectrum. It has longer wavelengths than visible light, making it invisible to the human eye.

Main breaker is responsible for controlling the flow of electricity from the utility into the home. It serves as a master switch that can disconnect power in the event of an emergency or when work is being done.

Northeast Energy Efficiency Partnerships (N.E.E.P.) helps develop and support energy efficiency programs that aim to reduce the overall energy use in homes, businesses, and public spaces.

Neutral and ground bars provide paths for grounding electricity and safely returning any excess current to the earth, protecting the home and individuals from electrical faults.

Pressure transducers are devices that convert physical pressure into a variable electrical signal, allowing systems to measure and respond to pressure changes accurately.

Radiation is the transfer of heat through electromagnetic waves.

Replacement, or full load, refers to systems that operate at their maximum output all the time, regardless of the actual demand.

Seasonal Energy Efficiency Rating (SEER) is the ratio of the cooling output of an air conditioner over a typical cooling season to the energy it consumes.

Seasonal Energy Efficiency Rating 2 (SEER2) is the ratio of the cooling output of an air conditioner over a typical cooling season to the energy it consumes, based on new testing standards as of January 1,2023

Solar Heat Gain Coefficient (SHGC) is the ratio of solar radiation passing through a window, door or skylight, compared to the solar radiation contacting the surface.

Temperature thermistors are temperature-sensitive resistors used to accurately calculate the temperature of coils, air, refrigerant lines and compressors.

A Special Thank You

This project stands as a testament to the power of collaboration and shared passion. We are deeply grateful to our industry partners for their invaluable contributions. Their support has helped build a curriculum that will serve as a cornerstone in the HVACR industry's transition to a fossil fuel-free future. As we look ahead, we encourage everyone to stay connected with these thought leaders, to remain informed on the latest innovations, and to continue pushing the boundaries of high-performance heat pump technology.

- Daniel Bracciano, SME; Author, Engineer
- Ty Branaman, CMHE, Love2HVAC
- Conduit Tech https://getconduit.com
- Daikin Comfort Technologies https://daikincomfort.com
- Fieldpiece Instruments https://www.fieldpiece.com
- Fujitsu General https://www.fujitsugeneral.com
- Kwik Model https://kwikmodel.com
- Patrick Murphy, CM, Quinn-Murphy Consulting, LLC
- Northeast Energy Efficiency Partnerships https://neep.org
- NYSERDA https://www.nyserda.ny.gov
- Pacific Northwest National Laboratories https://www.pnnl.gov
- Retrotec https://retrotec.com
- The Energy Conservatory https://energyconservatory.com
- US Department of Energy https://bsesc.energy.gov

Together, we are shaping a brighter, more sustainable tomorrow!

Chapter 1
Heat Pump Fundamentals

Objectives

After studying this chapter, you should be able to:

- compare the initial cost versus long-term costs of heat pump equipment.
- describe the fundamental principles of heat pump system operation.
- discuss the design options for various heat pump system applications.
- examine different heat pump configurations.
- identify key considerations when addressing consumer comfort and energy conservation.

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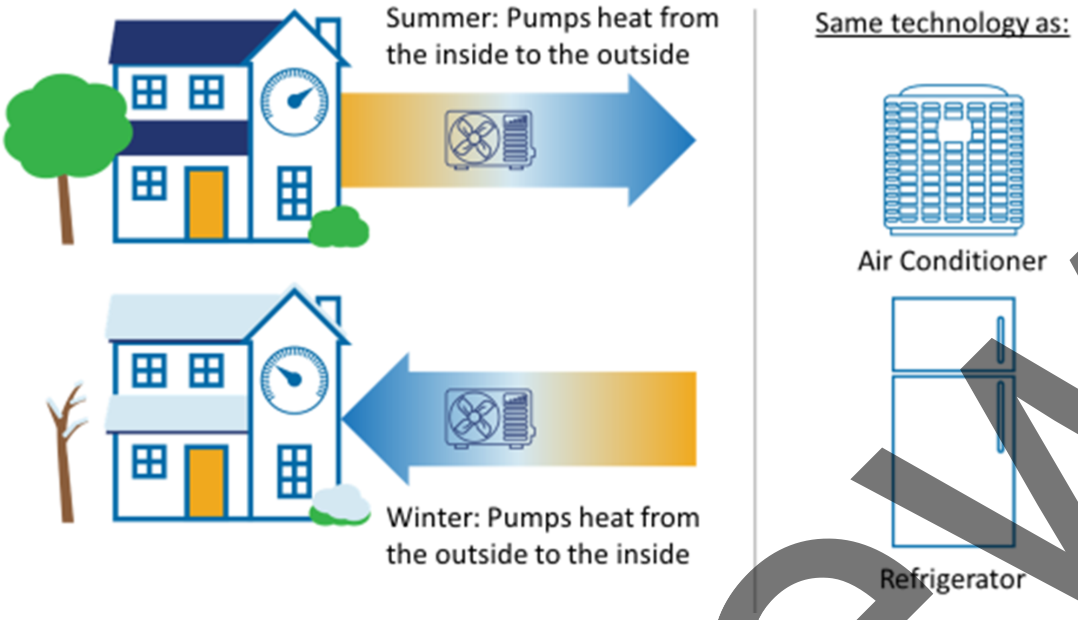

Figure 1-3. *A heat pump operates by transferring heat using a refrigerant.*

Where Does the Heat Come From?

Many people wonder where the heat comes from when a heat pump is running in cold weather. The answer lies in the fact that even cold air contains heat energy. In heating mode, a heat pump extracts heat from the outside air or ground, where the sun's energy has stored it, even if temperatures are low. The refrigerant in the system absorbs this heat and transfers it inside the home.

In cooling mode, the process is reversed. The heat pump doesn't bring in cold air; it removes heat from inside the home and releases it outdoors, leaving cooler air behind.

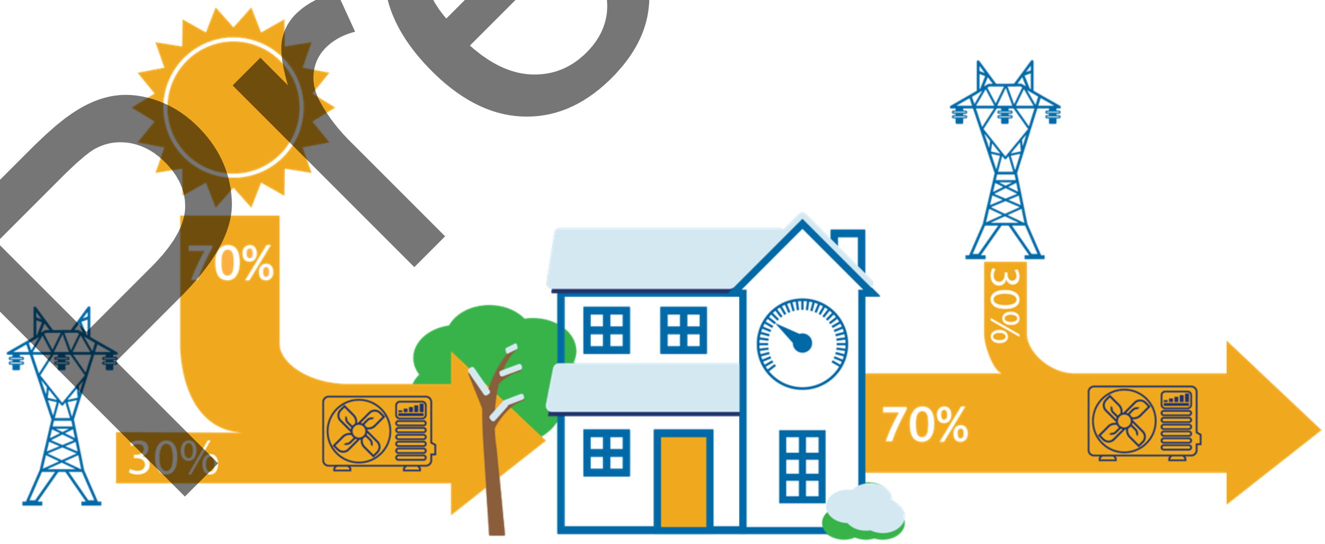

Figure 1-4. *In heating mode, a heat pump extracts heat from the outside air or ground, where the sun's energy has stored it, even if temperatures are low. The refrigerant in the system absorbs this heat and transfers it inside the home. In cooling mode, the process is reversed. The heat pump removes heat from inside the home and releases it outdoors. This example illustrates a heat pump moving 233% more heat energy than it uses in electrical energy, measured in watts.*

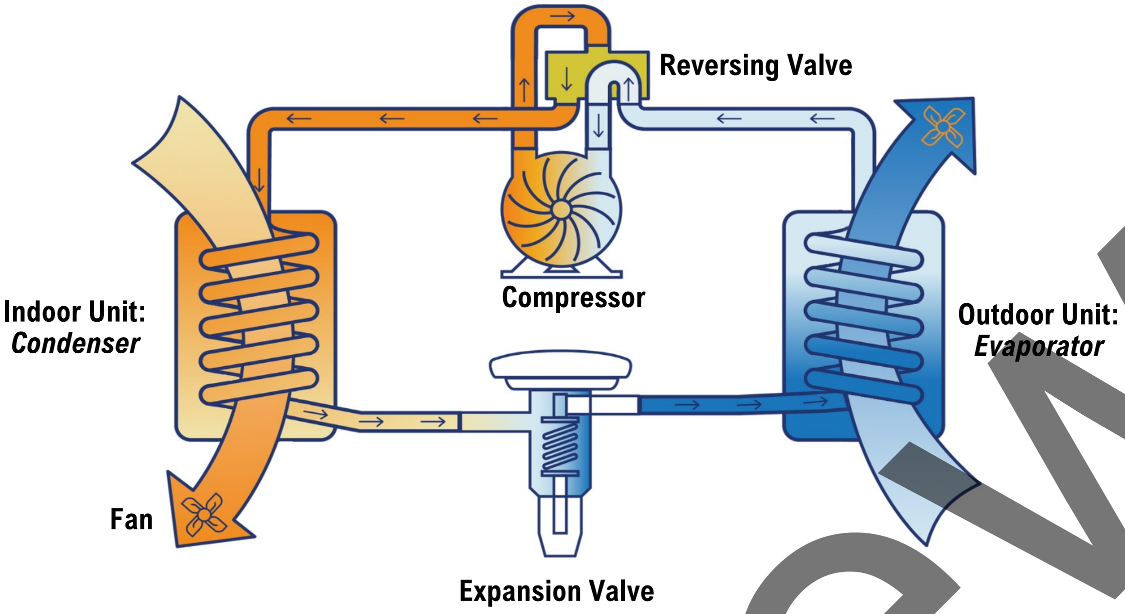

Figure 1-8. *Heat pump cycle.*

Evaporator	In heating mode this is the outdoor unit, where cool liquid refrigerant evaporates into warm gaseous refrigerant, pulling heat out of the air. In the summer, the indoor unit is the evaporator.
Compressor	Compresses warm gaseous refrigerant into hot-gaseous refrigerant, to send to the condenser for release.
Condenser	In heating mode this is the indoor unit, where hot-gaseous refrigerant condenses into warm liquid refrigerant inside the coil, releasing its heat in the process. In the summer, the outdoor unit is the condenser, releasing heat.
Fan	Blows air across the indoor unit's heating coil, helping to release the heat (in winter) or pull the cool air (in summer). It is how the energy is transferred from the unit itself into the house. The speed of airflow impacts that rate of energy transfer.
Metering Device	Regulates how much refrigerant flows through the refrigeration circuit overall. As warm-liquid refrigerant passes through it, it turns to cool-liquid due to lower pressures on the other side of the device and is now ready again to collect heat in the evaporator.
Reversing Valve	The four-way reversing valve changes the flow of refrigerant to the indoor or the outdoor coil. An electrically- operated pilot valve controls pressure on each side of the main slide valve (pilot valve may have 3 or 4 connections). There must be a minimum pressure difference of 75 PSI between the low and high sides to move the main slide valve. Under normal operating conditions, only refrigerant vapor flows through the reversing valve.

Design Considerations

In the world of heating, ventilation, and air conditioning (HVAC), the terms displacement and replacement often refer to different operational capacities of systems.

When planning for both types of systems, factors such as room size, usage, and local code requirements are critical. Proper placement of units and careful attention to equipment configuration can ensure an efficient, comfortable heating solution.

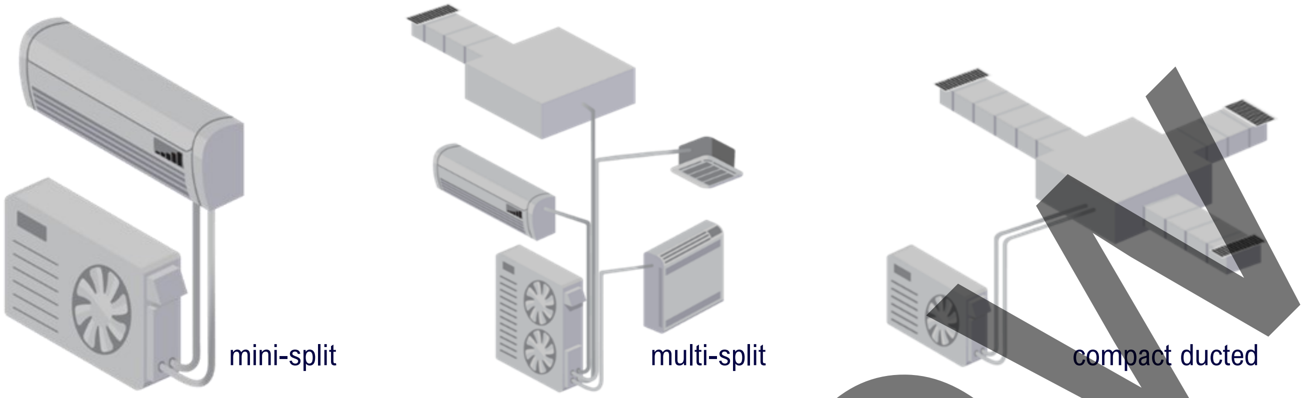

Figure 1-13. *Other design options including mini-split, multi-split and compact ducted.*

Other Considerations

When installing heat pump systems, both the outdoor unit's placement and the ductwork design are critical to ensuring efficiency, comfort, and longevity of the system. Key factors such as environmental conditions, airflow requirements, and equipment placement must be carefully considered. Outdoor heat pump units require protection from environmental factors like snow, wind, and ice. By carefully considering both outdoor unit placement and indoor airflow design, HVAC professionals can ensure that heat pump systems operate efficiently and provide consistent comfort throughout the home.

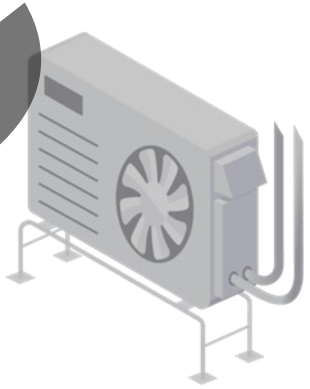

Figure 1-14. *Heat pump system installed on risers.*

Snow protection is vital in cold climates—installing units on risers or wall mounts prevents snow buildup and keeps the system operating efficiently. Additionally, units should be placed on gable ends of the home to avoid issues with roof-dump, where snow and water runoff from the roof could fall onto the unit.

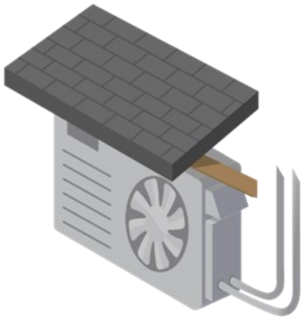

Figure 1-15. *Heat pump system with wind/debris protection.*

Wind and debris protection is also important. Avoid placing the unit in corners or areas where wind-eddies could trap leaves and debris. Proper condensate drainage planning (from the outdoor unit) ensures that defrost water can drain away without freezing or causing safety hazards on walkways.

Lineset considerations are essential to maintain system efficiency. The refrigerant line should be short, ideally no longer than 25 feet, and should be installed in a way that ensures it can easily reach the indoor unit without unnecessary bends or obstructions.

Figure 1-16. *Lineset considerations are essential to maintain system efficiency.*

Chapter 2
Inverter Operation

Objectives

After studying this chapter, you should be able to:

- determine the values of Inverter thermistors and transducers.
- compare the advancements in the HVAC industry to those of the auto industry.
- explain the components of an inverter system.
- summarize how an inverter board uses inputs and outputs to control capacity.
- describe the electrical functionality of an inverter control board.

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To understand inverter-driven refrigeration systems, we need to look at the industry's evolution. Early systems used open-drive vapor pumps powered by steam or internal combustion engines, with flammable, toxic, or high-pressure refrigerants like CO^2. Controls were basic, using blade switches and handlever-operated belts. By the 1920s, safer CFC and HCFC refrigerants were developed, along with pressure- or temperature-activated mechanical switches that controlled systems until the 1980s.

Modern systems now use solid-state controls and variable-speed motors, improving efficiency and reducing in-rush current at startup. Refrigerants have become more environmentally friendly, like HFOs and HCs. Solid-state drives control motor speed, such as VFDs (Variable Frequency Drives), ECMs (Electronically Commutated Motors), and VRF (Variable Refrigerant Flow) systems. Collectively these components create Inverter technology, which adjusts compressor motor speed to match heating or cooling needs, improving temperature control and energy efficiency.

Introduction to Early-Generation Heat Pump Components

The first generations of heat pumps were designed with basic efficiency components that were easy to maintain but offered limited performance compared to today's systems. The primary components, such as the compressor, outdoor fan, and indoor fan, were powered by Permanent Split Capacitor (PSC) motors. These motors, supported by run capacitors, and occasionally start capacitors, were used to assist with compressor motor startup.

For refrigerant control, metering devices were simple, typically a fixed orifice or a basic Thermostatic Expansion Valve (TEV/TXV). These devices provided basic control of the refrigerant flow, but with limited adaptability to varying load conditions.

In terms of defrost control, early systems relied on a mechanical defrost timer or sometimes a defrost switch. However, these controls were not always present in every system, and the defrost process was less advanced than in modern heat pumps.

While these early components were reliable and required minimal maintenance, their performance was not as efficient or adaptable as the advanced technologies used in today's heat pumps.

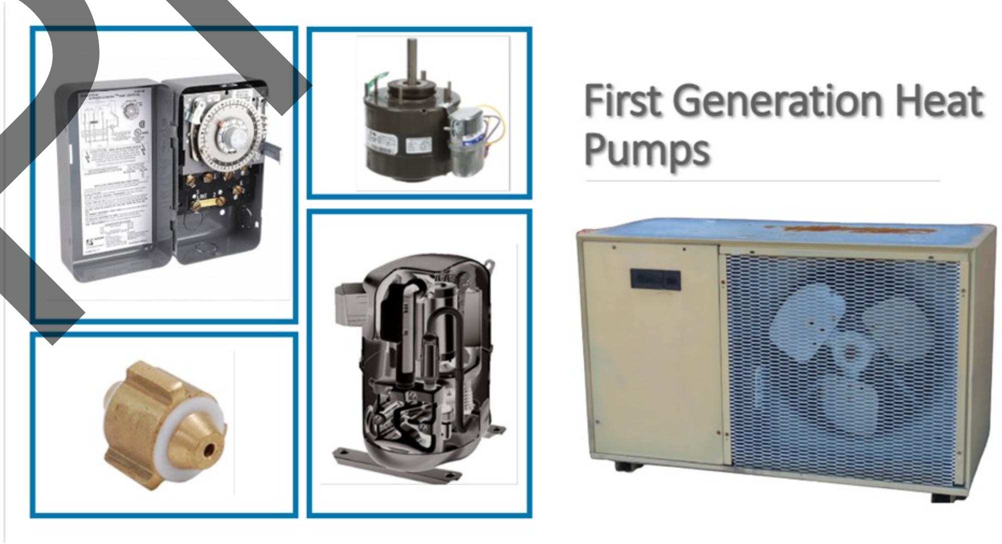


Figure 2-1. *Early generation heat pump and components.*

Heat exchanger thermistor is strategically placed within or near the heat exchanger to measure the temperature of the fluid or surface accurately. It operates by changing its electrical resistance in response to temperature variations. This change in resistance is converted into an electrical signal that the heat pump's control system processes. Using this data, the control system adjusts operational parameters such as compressor speed and refrigerant flow to enhance efficiency and performance. Additionally, this monitoring helps prevent problems like freezing or overheating, protecting the system and ensuring its longevity.


Figure 2-12. *A heat exchanger thermistor.*

Return air temperature thermistor is a crucial component in a heat pump system, helping it operate efficiently and maintain a comfortable indoor environment. The heat pump uses the return air thermistor to measure the space temperature and calculate system capacity needed to achieve thermostat setpoint.


Figure 2-13. *Return air temperature thermistor.*

Suction line thermistor(s) are placed in the refrigerant flow path to measure its temperature. As the refrigerant temperature changes, the thermistor's resistance varies accordingly. This change is converted into an electrical signal sent to the heat pump's control unit. The control unit uses this data to adjust the Electronic Expansion Valve (EEV), regulating refrigerant flow into the evaporator coil. This process optimizes the system's performance and energy efficiency by ensuring the evaporator coil operates at the ideal temperature.


Figure 2-14. *Suction line thermistor.*

Indoor coil thermistor is placed near the indoor coil of a heat pump to measure its temperature. It adjusts its electrical resistance with temperature changes, and this variation is processed by the control system. The control unit uses this data to optimize the heat pump's operation, adjusting settings like compressor speed and refrigerant flow for efficient indoor comfort. Additionally, it helps manage frost buildup in cooling mode to ensure proper system performance.

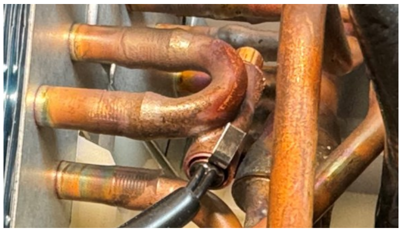


Figure 2-15. *Indoor coil thermistor.*

Defrost

Our previous generation of heat pumps typically used a temperature switch (defrost switch) initiated;, relay operated (defrost control board) to initiate a defrost cycle. At the opening of a defrost switch the timer would keep the defrost cycle initiated until time was met and the temperature switch closed once again confirming a successful defrost cycle. The more modern and efficient defrost cycle uses temperature thermistors to measure coil and ambient temperatures. The control board can now decide how often and how long to initiate a defrost cycle. In some very efficient controls, the system may use an off cycle defrost that requires little energy consumption.

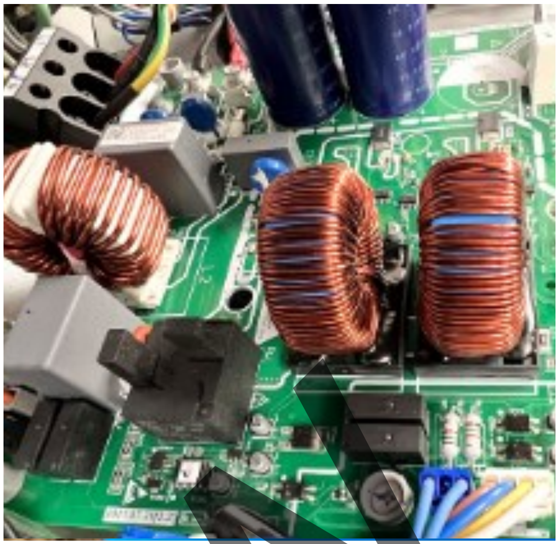
Chapter 3

Cold Climate Heat Pump Specifications

Objectives

After studying this chapter, you should be able to:

- calculate the energy consumption of a heat pump.
- distinguish the difference between the input energy and the output energy for a heat pump.
- compare equipment options for a home's heating load requirements.
- use extended heating data tables to determine system capacity.
- validate the performance of heat pumps with extended heating data tables.



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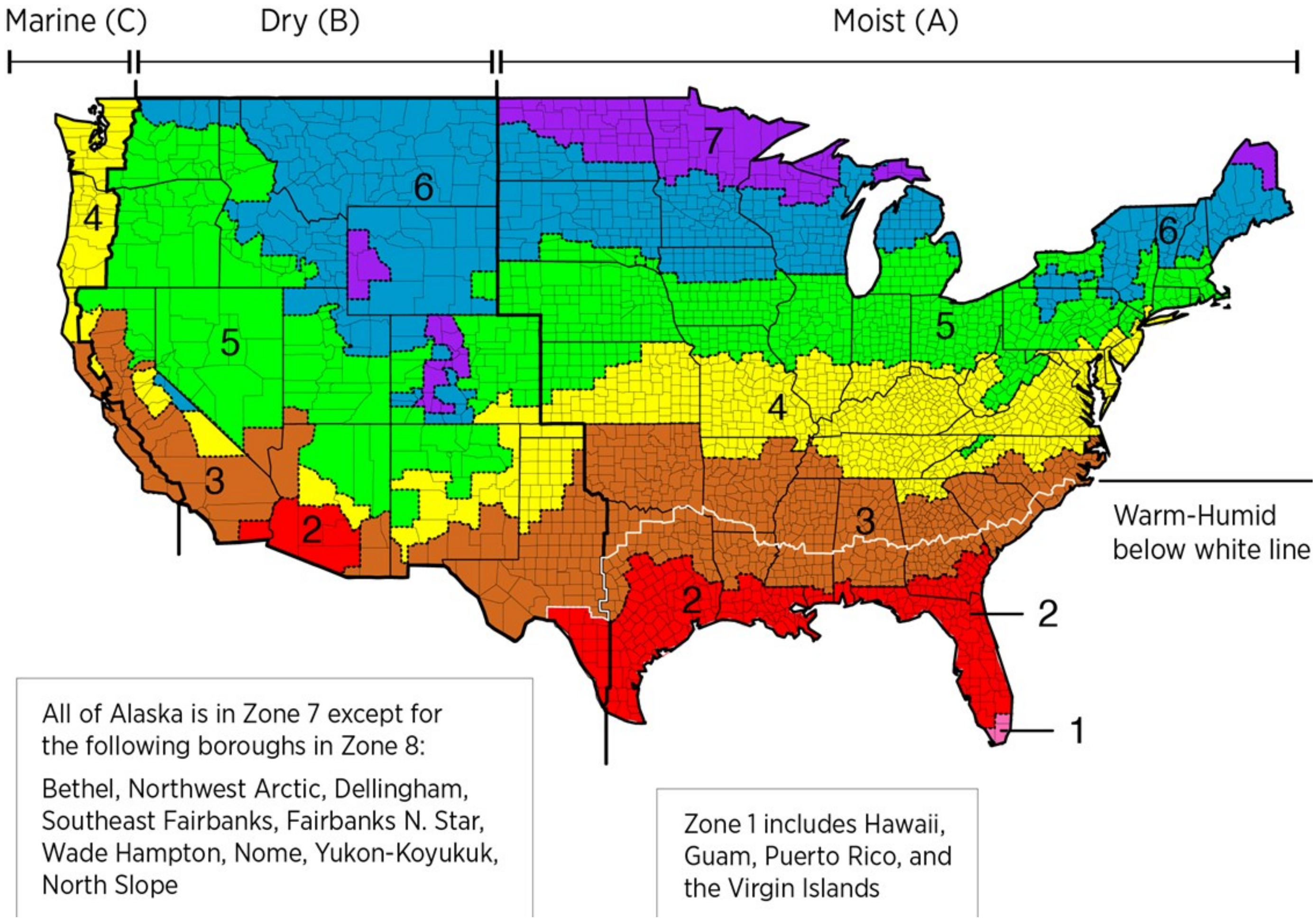
compare the energy cost of our heat pump versus that of our supplementary heat to determine at what point we may be able to sacrifice a margin of comfort to reduce energy costs. In comparison, electric resistive heating elements have an electrical efficiency of approximately 100%, giving them a coefficient of performance (COP) of 1.

IECC Climate Zones

The International Energy Conservation Code (IECC) was established in 1998 to address the energy efficiency of residential and commercial buildings. The code provides guidance to builders and contractors for ways to maximize energy efficiency in various climate sectors. The code establishes climate zones to assist in the determination of best practices and equipment selection as well as tools for improving the thermal envelope based on climatic conditions.



All of Alaska is in Zone 7 except for the following boroughs in Zone 8:

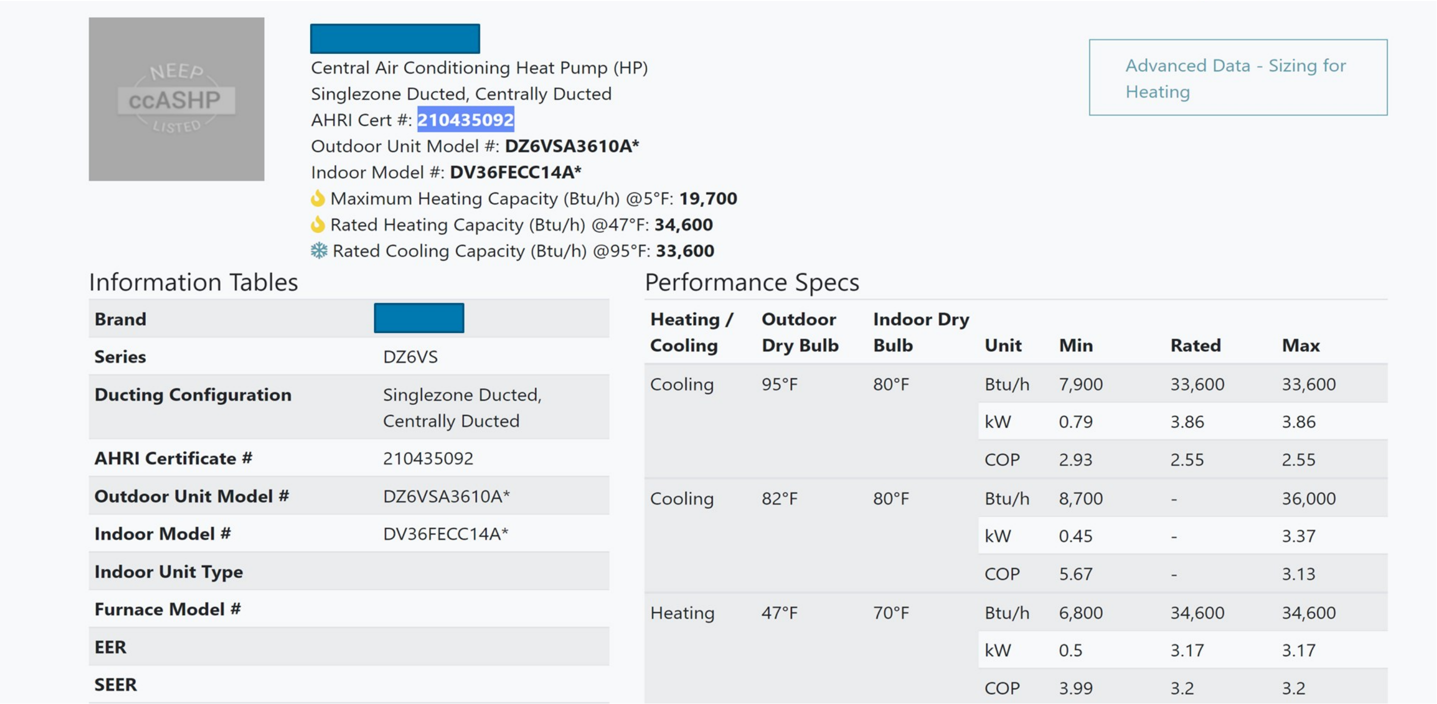
Bethel, Northwest Arctic, Dellingham, Southeast Fairbanks, Fairbanks N. Star, Wade Hampton, Nome, Yukon-Koyukuk, North Slope

Zone 1 includes Hawaii, Guam, Puerto Rico, and the Virgin Islands

Figure 3-3. *Climate zone map used to determine best equipment selection and codes based on climatic conditions.*

AHRI Tables

AHRI traditionally lists heating performance at 47°F, which is a critical standardized testing point for heat pumps. Understanding how these systems perform at this temperature allows for accurate comparisons and assessments across different models. By maintaining standardized testing conditions, AHRI ensures consistent and reliable performance data, enabling both consumers and industry professionals to make informed decisions.



[redacted]

Central Air Conditioning Heat Pump (HP)
Singlezone Ducted, Centrally Ducted
AHRI Cert #: 210435092
Outdoor Unit Model #: **DZ6VSA3610A***
Indoor Model #: **DV36FECC14A***
Maximum Heating Capacity (Btu/h) @5°F: **19,700**
Rated Heating Capacity (Btu/h) @47°F: **34,600**
Rated Cooling Capacity (Btu/h) @95°F: **33,600**

Advanced Data - Sizing for Heating

Information Tables

Brand	[redacted]
Series	DZ6VS
Ducting Configuration	Singlezone Ducted, Centrally Ducted
AHRI Certificate #	210435092
Outdoor Unit Model #	DZ6VSA3610A*
Indoor Model #	DV36FECC14A*
Indoor Unit Type	
Furnace Model #	
EER	
SEER	

Performance Specs

Heating / Cooling	Outdoor Dry Bulb	Indoor Dry Bulb	Unit	Min	Rated	Max
Cooling	95°F	80°F	Btu/h	7,900	33,600	33,600
			kW	0.79	3.86	3.86
			COP	2.93	2.55	2.55
Cooling	82°F	80°F	Btu/h	8,700	-	36,000
			kW	0.45	-	3.37
			COP	5.67	-	3.13
Heating	47°F	70°F	Btu/h	6,800	34,600	34,600
			kW	0.5	3.17	3.17
			COP	3.99	3.2	3.2

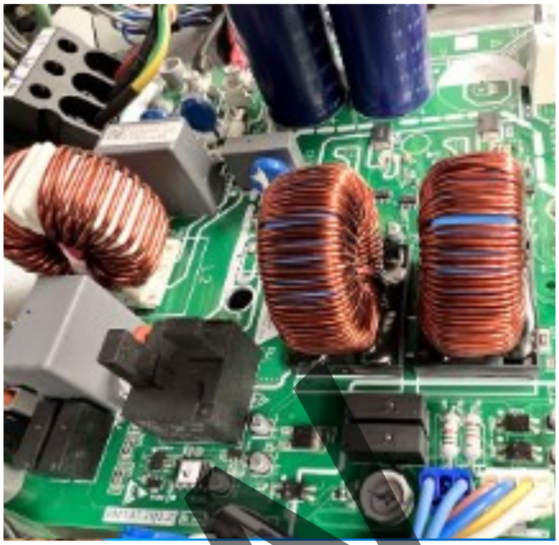
Figure 3-5. *The NEEP product listing and specification system will allow users to make comparisons of heat pump system variations, selecting assorted options that can lead to discovering brands or performance options not previously considered.*

This specification helps differentiate cold climate performance, offering a reliable benchmark for those tasked with installing, designing, or selecting heat pump equipment in challenging cold environments.

- Variable capacity, residential-scale, air source heat pump; ducted or ductless.
- High-rated heating efficiency (≥ 9 HSPF2 ductless, ≥ 10 HSPF2 ducted).
- High efficiency, even at 5°F (COP ≥ 1.75).
- Highly rated cooling efficiency.
- Capacity and efficiency data reported at multiple operating conditions.

Chapter 4

Smart Thermostats and System Efficiency



Objectives

After studying this chapter, you should be able to:

- calculate the balance point of a heat pump system.
- determine the proper settings for compressor lockouts and heating element lockouts.
- identify the droop setting of an HVAC control.
- interpret the wiring functions of legacy and communicating systems.
- review the setback temperatures used in various heat pump applications.

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Smart thermostats are integral to achieving the maximum potential efficiency of a high-performance HVAC system. Their ability to adjust to real-time conditions, automate schedules, provide data-driven insights, and integrate with other smart technologies makes them a crucial tool for both improving comfort and reducing energy consumption.

Ducted Heat Pump Thermostats

When it comes to controlling ducted heat pump systems, there are two primary types of thermostats: the traditional 24VAC platform, often referred to as "legacy," and the more modern communicating thermostats. Legacy thermostats use the familiar 24VAC wiring to control the system, while communicating thermostats operate with fewer wires and rely on a VDC network to exchange commands and messages between the various components of the system, commonly 5VDC or 12VDC. Each platform offers distinct advantages and operates in diverse ways, which we will explore in more detail later in this chapter.

Figure 4-1. *Modern communicating thermostat.*

Ductless Heat Pump Thermostats

There are four types of controllers that are most used for managing ductless heat pump systems. These controllers include the ductless wand or remote, wall thermostat, mobile app, and smart wall thermostat. Each controller offers unique features and varying levels of control and convenience.

Ductless Wand Controllers. Most ductless heat pumps (DHPs) include a handheld "wand" style controller resembling a remote control. This controller allows basic operational adjustments but is not the main thermostat interface, which is typically integrated into the indoor unit.

Figure 4-2. *Ductless wand controller.*

Wall-Mounted Thermostats. Some manufacturers offer wall-mounted thermostat-style controllers as alternatives. Depending on the brand, compatibility and additional components may be required to synchronize the thermostat's control settings with the indoor unit's temperature detection functions.

Figure 4-3. *Wall-mounted thermostat.*

Mobile Applications. Many top manufacturers provide mobile apps that enable remote system control, enhancing convenience for homeowners. It is essential to verify with your manufacturer representative regarding necessary components and specific model compatibility for using these apps effectively.

Figure 4-4. *Mobile application.*

Common Communicating Thermostat Connections

Many of today's modern communication platforms allow for fewer control wires to be connected to the system, creating a communication network. Others have taken a hybrid approach, like the ComfortBridge® system for Goodman/Amana, that uses 24VAC legacy wiring to the thermostat and communicating 2 wire DC to the outdoor unit.

Communicating wiring networks for unitary ducted HVAC equipment, regardless of manufacturer, operate on similar principles. One of the most critical factors for reliable communication in these systems is proper grounding, according to your equipment installation instructions. Without a solid ground, communication voltages can become distorted or fail entirely, leading to system faults. Additionally, it is important to follow the manufacturer's guidance regarding the use of shielded versus non-shielded wire, as improper use can introduce electromagnetic interference (EMI) and cause communication disruptions.

Common issues like poor ground connections or corroded wire nuts are among the top reasons for communication failures, making it crucial to minimize the number of wire connections and avoid unnecessary wire loops during installation.

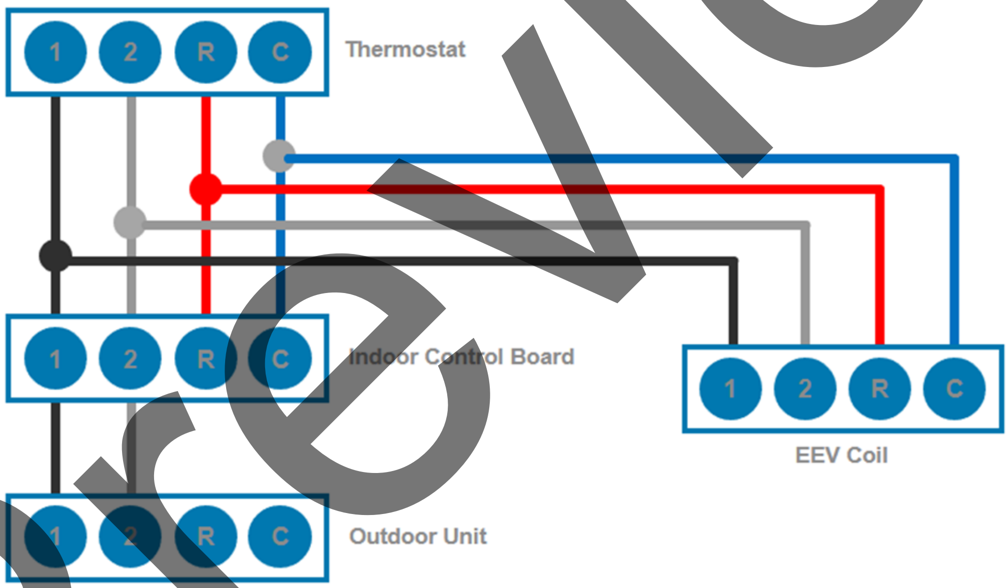
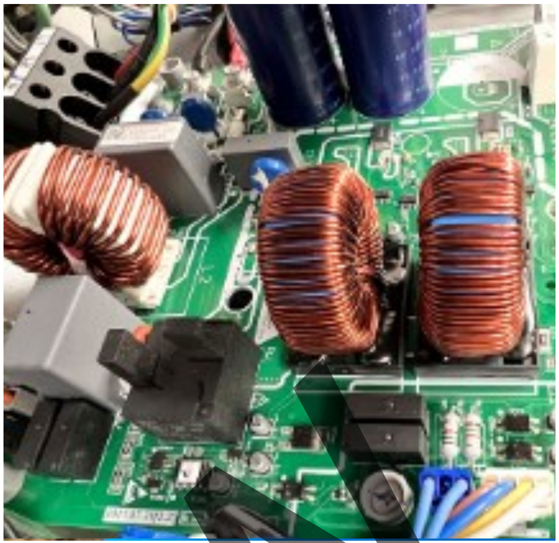


Figure 4-13. *Proper grounding is KEY to a proper communicating system. Without proper grounding, voltages can be obscured, and communications may fail or be indistinguishable, causing faults.*

Common Ductless Connections

Ductless systems typically use a four-wire cable to connect the outdoor unit to the indoor unit. High voltage is supplied through connections L1 and L2, while a DC communication signal is transmitted via terminal #3 (S). This communication signal is crucial for the system’s coordination and is typically measured between L2 and S. Since the DC signal shares the current path with the AC line on L2, it’s essential to carefully follow the manufacturer’s service instructions for accurate testing of the DC communication circuit.

Chapter 5
Ducted Heat Pump Systems



Objectives

After studying this chapter, you should be able to:

- calculate the total external static pressure of a ducted system.
- evaluate the effects of total external static pressure on ducted inverter systems.
- examine the newest technologies for measuring a home's efficiency.
- identify key measurements needed for providing total home performance solutions.

HIGH PERFORMANCE HEAT PUMPS

Figure 5-5. Flow hood.

Flow Hood. Passive flow hoods extend the ductwork, allowing airflow to pass through and be measured, provided they are used properly without significant insertion loss. They are best used for recording CFM through a single return. In contrast, powered flow hoods offer high accuracy by compensating for back pressure, making them ideal for measuring CFM on supply ducts to balance airflow effectively.

Traverse Measurement. A traverse involves determining airflow velocity by taking measurements across different points in the duct using either a pitot tube, hot wire anemometer, or vane anemometer. After measuring velocity, CFM is calculated using the formula: CFM = Velocity x Area.

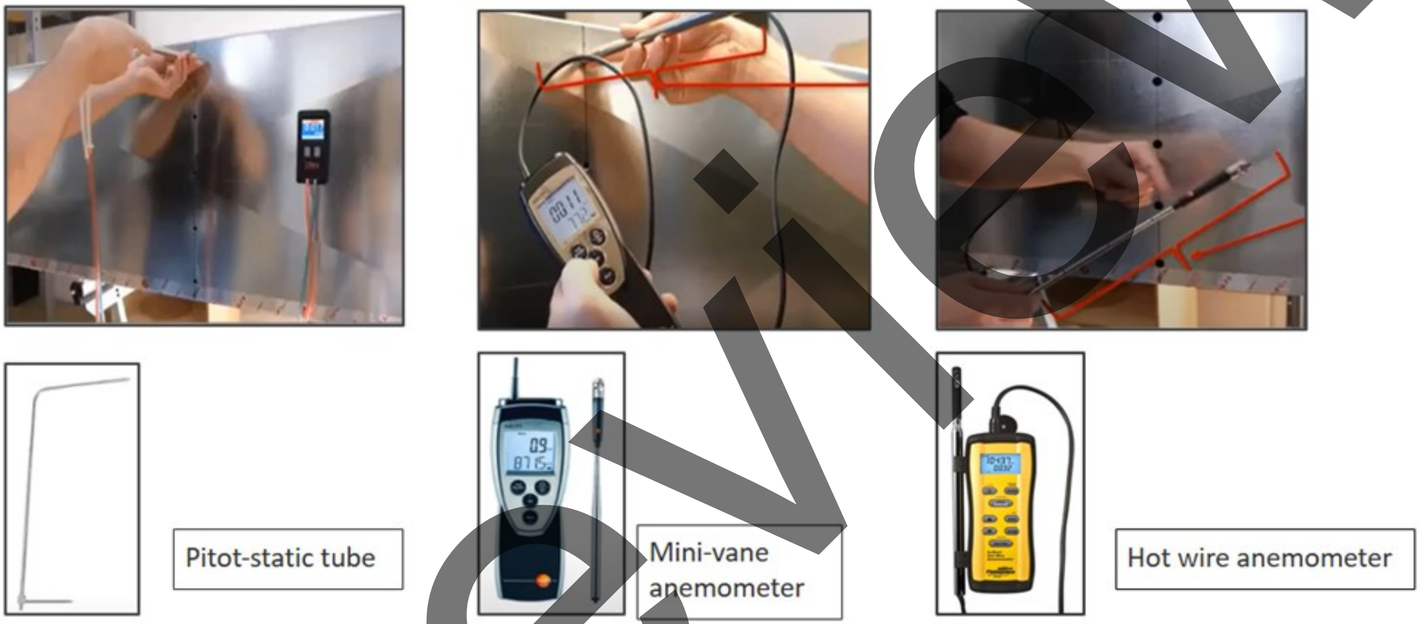


Figure 5-6. A traverse involves determining airflow velocity by taking measurements across different points in the duct using either a pitot tube, hot wire anemometer, or vane anemometer.

True-Flow Grid®. The digital TrueFlow comes with a Bluetooth manometer and a Bluetooth grid. These two items used together can produce a flow measurement by using static pressures taken inside the duct system and a flow measurement from the grid. These static pressure(s) and flow measurements will be displayed on the app that accompanies the tool. The app is called TrueFlow and can be downloaded fromthe Apple or Android App stores for free. Pressure and flow recommendations will be given inside the app to assist a technician for repairs.

Figure 5-7. True-Flow Grid® kit.

Chapter 6
Ductless Heat Pump Systems

Objectives

After studying this chapter, you should be able to:

- evaluate the heat load for individual spaces to assure proper equipment selection.
- identify the appropriate locations for system components within a home to maximize system performance.
- differentiate between AC and DC voltages in a ductless system.
- identify electrical circuits by utilizing an equipment manufacturer's application and installation manuals.

Communication

In many ductless systems, both AC and DC simulated voltages are present on the common line. For a 240VAC unit, L2 supplies power, while L1 supplies power for a 120VAC unit. The AC sine wave is shifted vertically due to the DC simulated signal, which can be generated either positively or negatively relative to ground. This arrangement allows for effective operation and control of the system's electrical components, ensuring proper voltage levels and functionality as needed by the unit's design and specifications.

Pulse distance encoding is a method of encoding data where information is conveyed by measuring the time gaps between pulses. Instead of using changes in signal strength or frequency, it uses the duration between pulses to represent ones and zeros. This approach is widely used in digital communications for efficient data transmission, ensuring precise timing and effective use of bandwidth in various technologies like telecommunications, HVACR communications and computer networks.

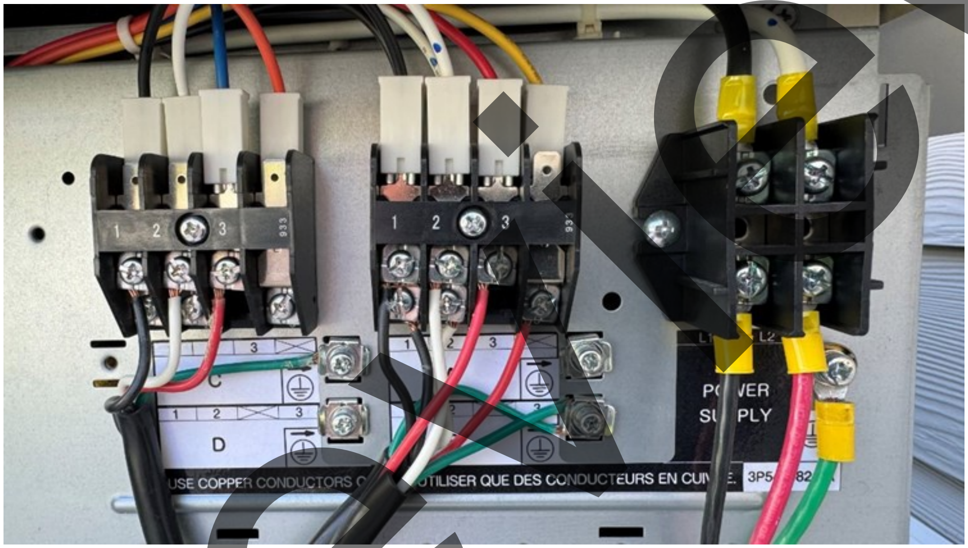


Figure6-5. *In a ductless system, the EEV is typically located in the outdoor unit, but in the case of a multi-zone system, each individual circuit has its own dedicated EEV.*

Infrared (IR) Remotes

Many ductless systems use wand style remote controls to operate the system. Infrared (IR) remotes use a specific pulse distance encoding system to communicate with the indoor unit of HVAC systems. The IR transmitter sends out a series of pulses, and the timing or distances between these pulses dictate the commands given to the IR receiver on the indoor unit.

IR communications rely on the transmission and reception of data through infrared light, which is invisible to the human eye. These signals are emitted by an infrared LED, typically operating at a wavelength of around 950 nanometers. Communication is achieved through modulating the IR light, meaning the LED pulses on and off to represent binary data. However, to avoid interference from other IR sources, more complex pulse patterns are used. This allows the indoor unit to detect and interpret the commands accurately, ensuring smooth communication between the remote and the unit.

7. What is the advantage of using a hybrid HVAC system that integrates both ducted and ductless components?
   - A. Lower cost than traditional systems.
   - B. Flexibility in zoning and installation.
   - C. Reduced need for maintenance.
   - D. Increased power consumption.

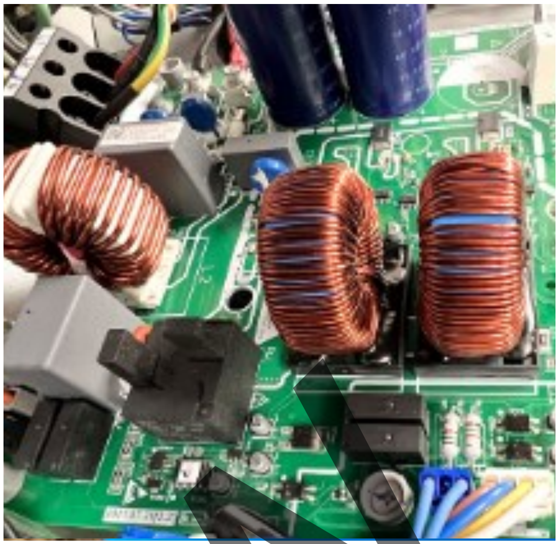
8. The function of the cooling loop in an inverter control board for units above 36,000 BTU is to;
   - A. cool the refrigerant for use in the defrost cycle.
   - B. remove the control board's excessive heat.
   - C. filter air.
   - D. increase system capacity.

9. The method in which data is transmitted by measuring the time gaps between pulses is called;
   - A. frequency modulation.
   - B. pulse distance encoding.
   - C. voltage modulation.
   - D. binary pulse synchronization.

10. The purpose of the vertical shift in the AC sine wave in a ductless system is to;
   - A. reduce the current flow.
   - B. simulate DC signals relative to ground.
   - C. increase the voltage.
   - D. protect the system from power surges.

Chapter 7

Retrofitting Fossil Fuel Systems



Objectives

After studying this chapter, you should be able to:

- examine the factors that affect the home energy audit.
- calculate an electrical panel's size requirement when considering a heat pump upgrade.
- identify the basic requirements of performing a heating load calculation.
- explore the different resources available for performing a heating load calculation.
- point out key considerations for performing an accurate load calculation.

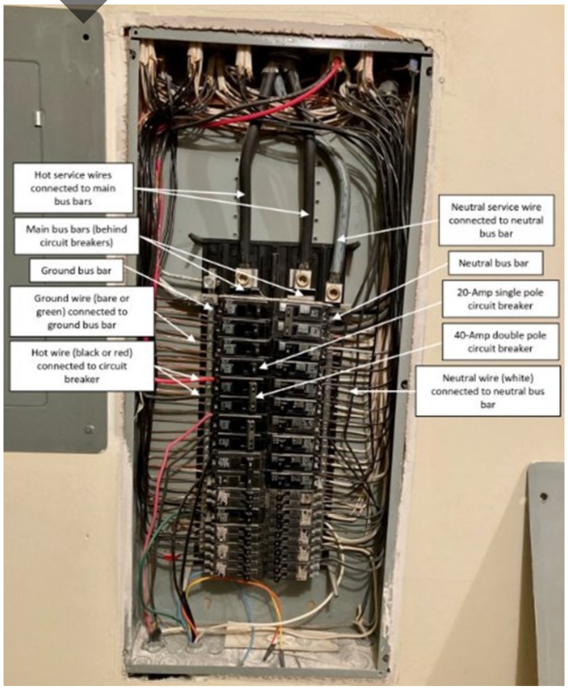
HIGH PERFORMANCE HEAT PUMPS

To begin retrofitting a heating system, the initial step involves evaluating the current equipment and performing an energy audit. This process is essential for understanding the efficiency, capacity, and energy usage of the existing fossil fuel system. By conducting an energy audit, homeowners gain valuable insights into their heating requirements and assess the potential benefits, cost savings, and environmental advantages of transitioning to a heat pump system. This evaluation forms the foundation for informed decision-making regarding the upgrade to more efficient heating technology. Before installing a heat pump, conducting a thorough inspection of the electrical panel, and performing a load calculation is crucial to ensure the current electrical service can accommodate the new demand.

Safety Precautions

Before starting, it is essential to prioritize safety. Wearing protective gear, such as gloves, safety glasses, and appropriate clothing, is necessary. Make sure the area around the panel is clear and accessible to prevent accidents. Only trained individuals should handle or work inside the panel, as there are risks of electrical shock or injury.

Key Components of the Electrical Panel



The **main breaker** is responsible for controlling the flow of electricity from the utility into the home. It serves as a master switch that can disconnect power in the event of an emergency or when work is being done.

Circuit breakers are designed to protect each individual circuit from being overloaded. If too much current flows through, the breaker will trip, cutting off the power to prevent damage.

The **bus bars** distribute electricity from the main breaker to the different circuits in the panel, ensuring power reaches all parts of the home.

Neutral and ground bars provide paths for grounding electricity and safely returning any excess current to the earth, protecting the home from electrical faults.

Visual Inspection

When inspecting the panel, start by checking the enclosure for any signs of physical damage, rust, or corrosion, which could compromise its integrity. Inspect the wiring for issues such as overheating, frayed wires, or loose connections, as these could lead to system failures or safety hazards. Additionally, look for any tripped breakers, which may signal that certain circuits are being overloaded. Lastly, verify that all labels on the panel are clear and correctly identify the circuits for easy reference during repairs or emergencies.

Calculate The Following

- 2,500 square feet x 3 VA = 7,500 VA for lighting
- 3 appliance circuits x 1,500 VA each = 4,500 VA
- The general loads (range, dishwasher, and clothes dryer) can be added at their wattage rating as VA: 5,000 VA + 1,000 VA + 5,600 VA = 11,600 VA

Apply the demand factor to general loads
10,000 VA x 100% = 10,000 VA
1,600 VA x 40% = 640 VA
Subtotal of general load is 10,640 VA

Add lighting and appliance circuits to the general load: 7,500 + 4,500 + 10,640 VA = 22,640 VA

Add the heating load to the general load: 22,640 VA + 15,000 VA = 37,640 VA

Divide total VA by 240V to get amps: 157A

Example #2: Now assume you want to add a 3-ton heat pump unit with 40-amp breaker to replace the baseboard heaters and add cooling. Will your electrical load exceed the home's 200A service? Are you reducing or increasing the overall electrical load by adding the heat pump? Redo the calculation removing the baseboard heating and adding in the heat pump.

2,500 square feet x 3 VA = 7,500 VA for lighting
3 appliance circuits x 1,500 VA each = 4,500 VA

The general loads (range, dishwasher, and clothes dryer) can be added at their wattage rating as VA:
5,000 VA + 1,000 VA + 5,600 VA = 11,600 VA

Apply the demand factor to general loads:
8,000 VA x 100% = 8,000 VA
3,600 VA x 40% = 1,440 VA
Subtotal of general load is 9,440 VA

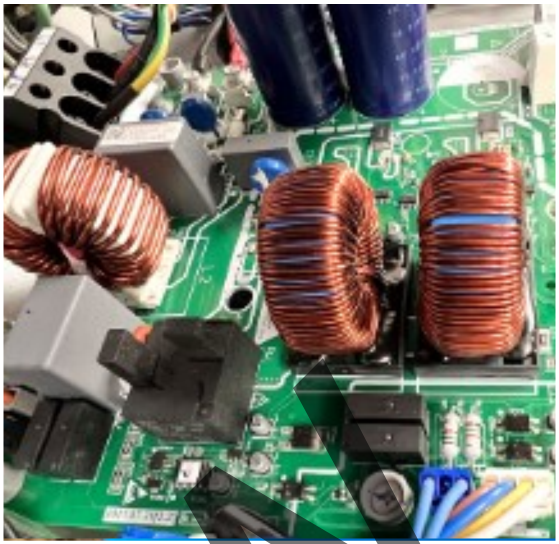
Add lighting and appliance circuits to the general load: 7,500 + 4,500 + 9,440 VA = 21,440 VA

Divide total VA by 240V to get amps without heating: 89A

Add in the Amps of the heat pump: 89A + 40A = 129A

Conclusion
Adding the heat pump will not exceed the home's 200A service and reduces the overall electrical load.

Chapter 8
Heat Pump Design and Selection



Objectives

After studying this chapter, you should be able to:

- calculate duct leakage CFM, from a home or other structure.
- Integrate industry recommended practices for ccASHP system design.
- compare various system design options to create the best solution for the consumer.
- identify key design considerations for mini-split and multi-zone ASHP applications.
- explore common design failures experienced by seasoned professionals.

The efficiency of a home's heating and cooling system is influenced by several key factors related to the building's structure and design. Understanding these elements helps optimize energy use, reduce costs, and improve overall comfort.

Building envelope issues should be addressed prior to the selection and sizing of a new heat pump system. This can allow for smaller, and less expensive, heat pumps, and ensure the system is not oversized for the home’s actual need. This will also make it easier to match available heat pumps to the home’s overall load and energy need across all conditions. A leaky, high-load house requires a larger heat pump to cover the peak-heating need, which inevitably leads to an oversized heat pump for more mild-conditions.

Key Factors Affecting Heating and Cooling Efficiency

- **Foundation.** The type and insulation of the foundation determines the amount of heat that escapes or enters from the ground. Insulated foundations are crucial for minimizing heat loss in colder climates.
- **Ductwork.** Properly designed and maintained ductwork ensures efficient heat distribution. Leaks or poor insulation in ducts can result in energy waste and uneven heating.
- **Exterior Walls.** The insulation of exterior walls, measured by their R-value, plays a significant role in resisting heat transfer. Higher R-values mean better insulation and less heat loss or gain.
- **Attic and Roof.** Adequate insulation in the attic and roof prevents heat from escaping through the top of the house. Ventilation is also important to reduce heat buildup in warmer months.
- **Wind Exposure.** Homes exposed to high winds lose more heat through exterior walls. Planting windbreaks or using landscaping features can help reduce this effect.
- **Directional Orientation.** The way a home is positioned relative to the sun and prevailing winds affects heat gain in summer and heat loss in winter. Proper orientation can optimize natural heating from sunlight.
- **Windows.** Windows' design and materials impact thermal performance. Double-pane or low-E glass windows reduce heat loss and improve energy efficiency. U-factors and solar heat gain coefficient (SHGC) further define how much heat passes through windows.
- **Floors.** Insulating floors, especially in contact with the ground, prevent unnecessary heat loss. The type of flooring material also impacts heat retention.
- **Thermal Envelope.** The overall tightness of the home’s thermal envelope—comprising walls, windows, doors, and insulation—determines how well a house retains heat in winter or stays cool in summer.

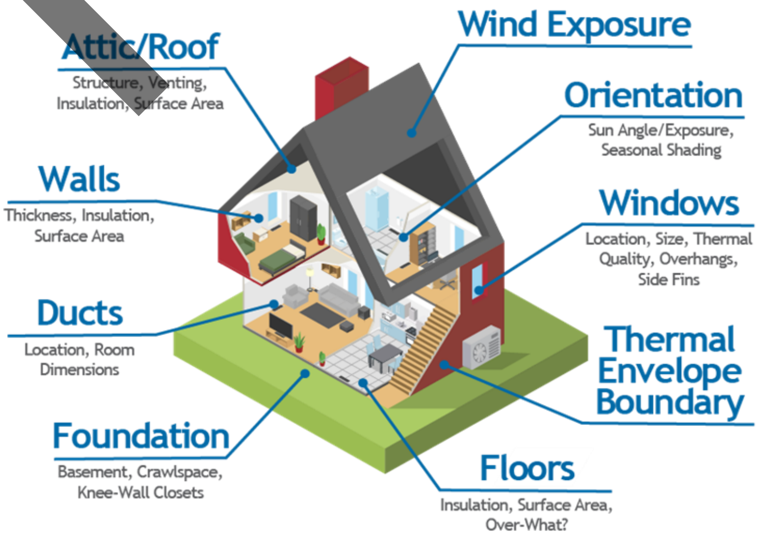


Figure 8-1. *Key factors that can effect the efficiency of the heating/cooling system.*

Comfort and Indoor Air Quality

- **Uneven Temperatures.** Leaky ducts can cause some rooms to be warmer or cooler than others, as conditioned air does not reach all areas evenly.
- **Poor Air Quality.** Leaking ducts can pull unfiltered air from unconditioned spaces like attics or crawl spaces, introducing dust, allergens, and pollutants into the indoor air. This can exacerbate respiratory problems and allergies.

Building Pressurization Issues

- **Pressure Imbalances.** When ducts leak outside the conditioned space, it can create negative pressure indoors. This pulls outdoor air into the building through cracks and gaps, reducing energy efficiency and further degrading air quality.

Mitigation Strategies

- **Duct Testing.** Conduct tests, such as a duct blaster test, to measure leakage levels and identify problem areas. Proper testing ensures compliance with energy codes and improves system performance.
- **Seal Ducts.** Use mastic, specialized duct tape, or aerosol sealants to reduce leaks at connections, joints, and transitions in the ductwork.
- **Insulate Ducts.** Adding insulation to ducts in unconditioned spaces can prevent heat loss or gain through the duct walls.

Total Duct Leakage

Total duct leakage refers to the amount of air that escapes from a duct system through holes, seams, and connections. This leakage can significantly impact on the efficiency and performance of HVAC systems.

Blower Door Test

A blower door test is a diagnostic tool used to measure the air tightness of a building and identify areas where air leaks are present. It helps assess how much air escapes through gaps, cracks, or other openings in the building envelope, which can affect energy efficiency, indoor air quality, and comfort.

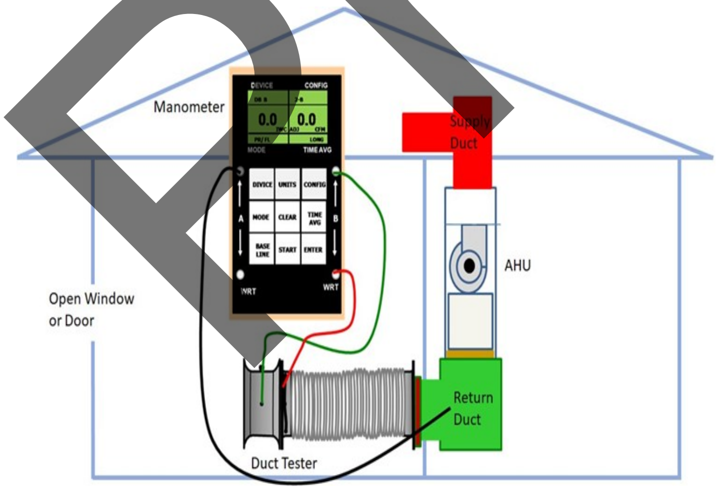


Figure 8-3. *A total duct leakage test measures the amount of air leaking from a building's ductwork.*

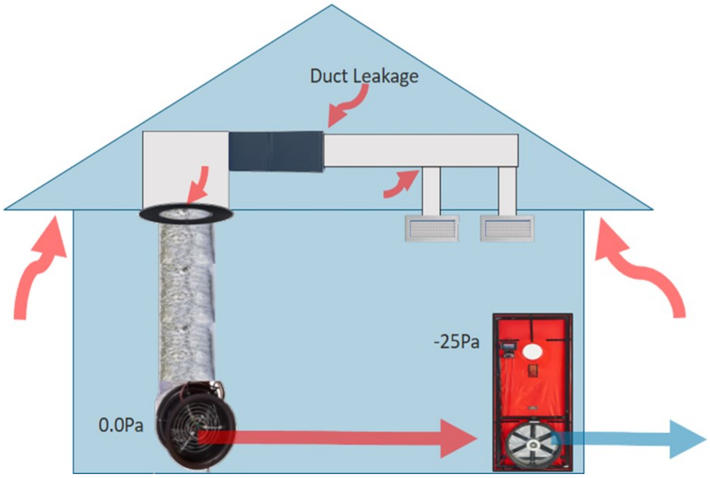


Figure 8-4. *A blower door test is a diagnostic tool used to measure the air tightness of a building and identify areas where air leaks are present.*

Heat Pump Selection

The first goal in heat pump selection and sizing is to understand the homes heating load on the coldest day of the year, as well as the cooling load on the hottest day of the year. The second goal in heat pump selection and sizing is to understand the heating load on mild days, to best match the equipment selection with the varying heating loads seasonally. The third goal in heat pump selection and sizing is to choose the right product that has optimal system efficiency and features for the consumer at an affordable price for them.

Recommended Practices for Sizing

Traditionally, HVAC trades are more concerned with under-sizing a system than oversizing. It is common to include safety factors or consistently apply “worse case” assumptions that drive towards a higher load calculation than is the reality. Cold climate heat pumps, due to their ability to modulate, need to be sized relative to precise load calculations.

- Determine customer’s preferences
- Assess current heating and cooling system as well as home layout
- Conduct load calculations; whole home (block load) and/or zonal
- Determine properly sized heat pump
- Determine optimal system design
- Integrate with backup and/or supplemental heating
- Set up controls
- Install as per specification
- Commission (test) the system

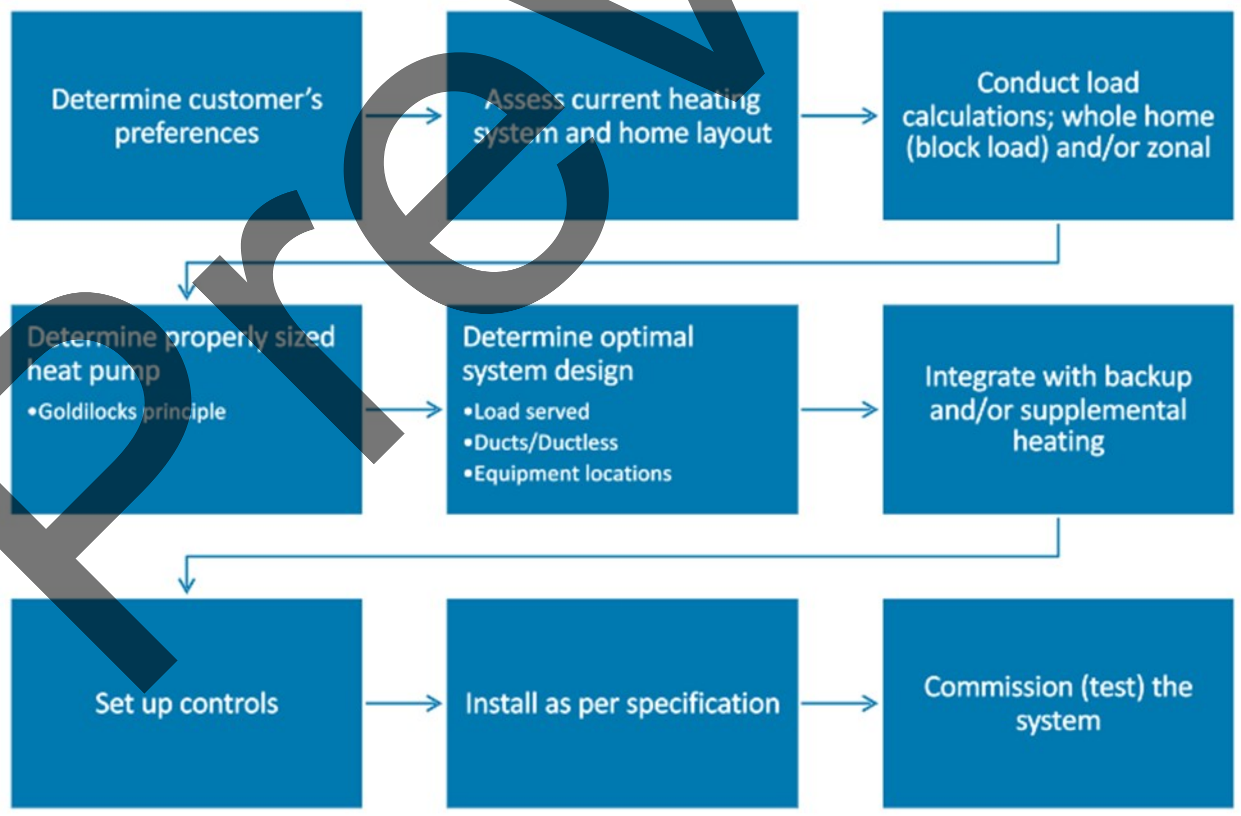
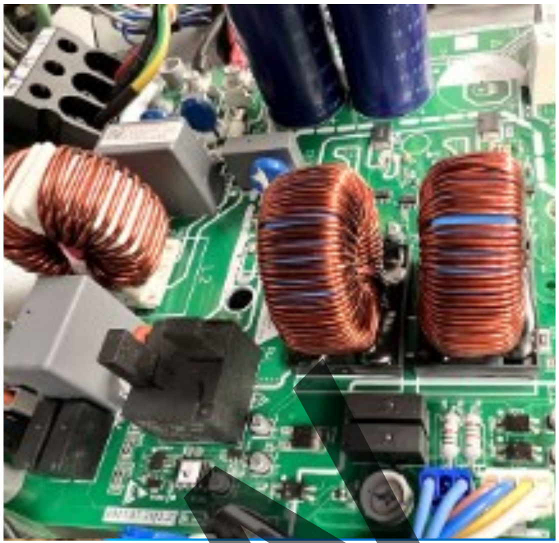


Figure 8-12. *Recommended sizing process. The middle row, steps 4, 5 and 6, all occur concurrently to some degree, informing each other. If you know you are going to use supplemental heat, you will choose a differently sized heat pump and a different design setup.*

Chapter 9

Heat Pump Installation Best Practices



Objectives

After studying this chapter, you should be able to:

- determine the most ideal installation location for a heat pump system's components.
- explain the benefit of modern flaring and torquing practices.
- examine OEM installation manuals for proper flaring torque values.
- identify the most applicable system accessories to help maximize system performance and efficiency.
- determine proper refrigerant charge using OEM specifications.

- **Drainage.** Provide adequate drainage around the outdoor unit to prevent water accumulation, which can freeze and cause damage during colder months.

Drain Pan Heater

In areas where the outside air temperature drops below freezing for an extended period, consider installing a drain-pan heater on the bottom frame to prevent drain freezing. The optional heater is advisable based on local conditions, and the installer should assess its necessity. Avoid using a concentrated or commonly piped drain to prevent freezing. If there is an issue with drain dripping, use a roof below the outdoor unit or implement other countermeasures. The Drain pan heater will cycle based on outdoor ambient temperature and system run time. Some manufacturers will leave the heater energized anytime the outdoor temperature is below a specific temperature, others will use ‘Smart Defrost” timing cycles.

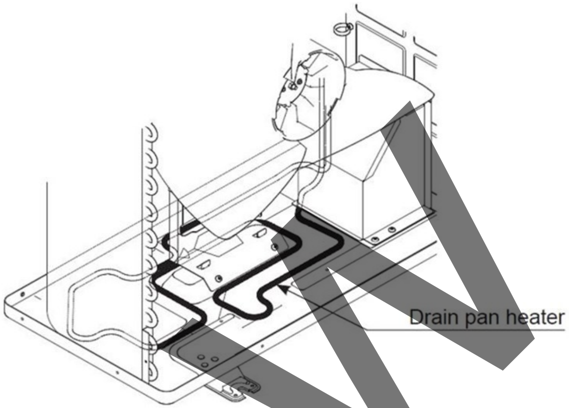


Figure 9-3. *In areas where the outside air temperature drops below freezing for an extended period, consider installing a drain-pan heater on the bottom frame to prevent drain freezing.*

Communication Interference

Inverter-type air conditioners sometimes cause static in other electrical appliances. When selecting an installation location, make sure the air conditioner and all wiring are sufficiently far away from radios, computers, stereos, and other appliances. Always verify proper grounding of the outside disconnect by testing voltage from L1-L2 (240VAC), L1-G (120VAC) and L2-G (120VAC).

- Ensure the air conditioner and all wiring are placed sufficiently far away from sensitive electronics.
- Avoid routing power cables near signal cables for radios, computers, and stereos.
- Consider using shielded cables or conduits if necessary to reduce interference.

Surge Protection

Implementing inverter Surge Protection Devices (SPD) is crucial to prevent damage to expensive inverters and connected electronics. They help ensure the reliability and longevity of the power conversion system, especially in areas prone to electrical disturbances or lightning activity.

- Place SPDs close to the inverter to minimize the path of the surge.
- Ensure proper grounding to enhance the effectiveness of protection.
- Follow manufacturer instructions for optimal placement and connection.

Figure 9-4. *Implementing inverter surge protection is crucial to prevent damage to expensive inverters and connected electronics.*

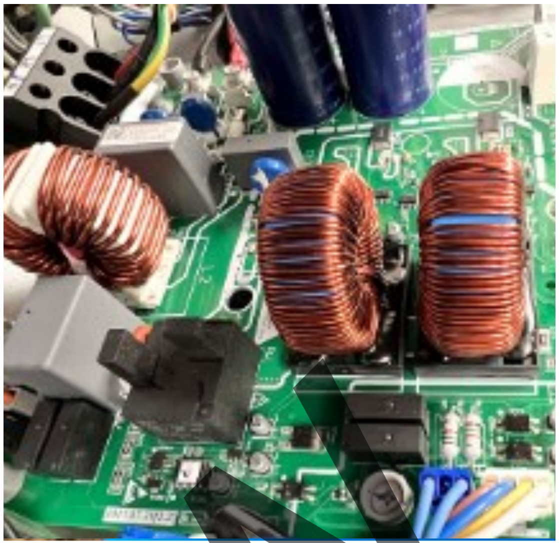
Refrigerant Charging

Many inverters will require being run in ‘charge mode’, either by menu setup from the outdoor unit or a communicating thermostat command, to add additional refrigerant. This command will initiate a 100% call for cooling, allowing system subcooling to be verified while making final refrigerant adjustments. Some manufacturers use a refrigerant charge adjustment table, based on lineset length, and recommend this charge be added while the system is still in a state of vacuum, before opening system service valves.

Figure 9-11. *Charging of ALL inverters is specific to the equipment being installed. Always refer to the installation manual for proper charging design and additional refrigerant charge (if applicable).*

Chapter 10

System Commissioning with Smart Diagnostic Tools



Objectives

After studying this chapter, you should be able to:

- calculate the operating capacity of an HVAC system.
- identify the importance of high-performance installations.
- create a system performance report with the use of smart diagnostic tools.
- provide a system performance report to the customer as a validation tool.
- utilize smart diagnostic tools and onboard diagnostic tools for equipment troubleshooting.

HIGH PERFORMANCE HEAT PUMPS

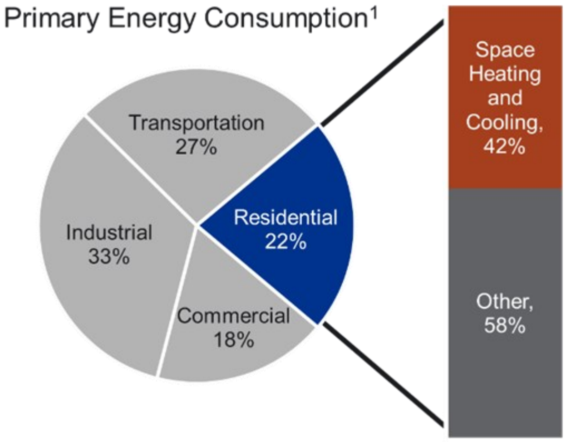


Figure 10-2. *Residential energy consumption accounts for 22% of our total energy use.*

Smart Diagnostic Tools

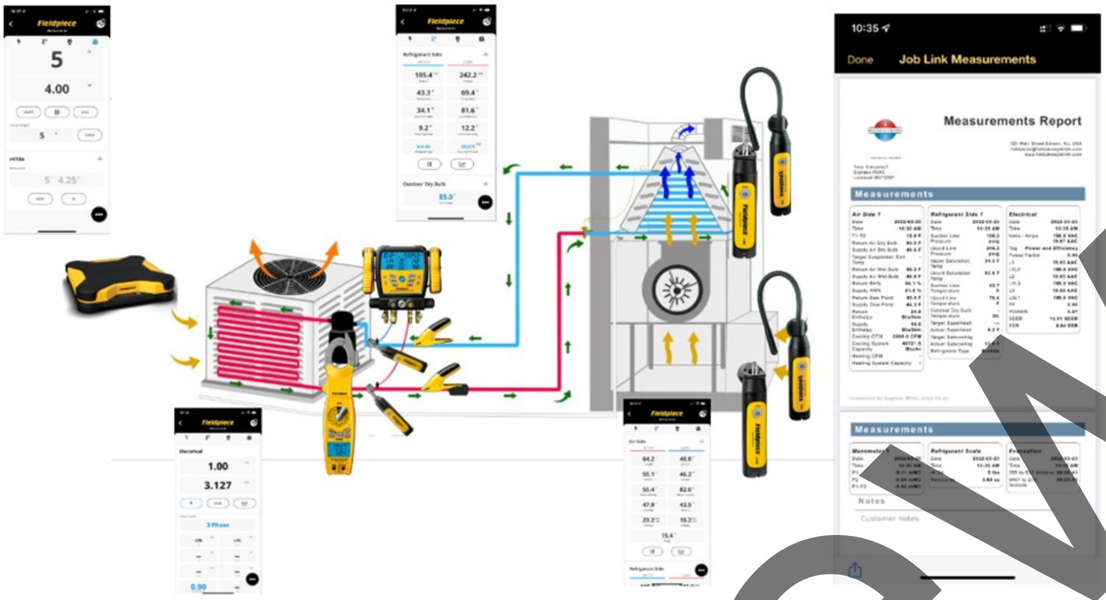
The HVACR industry has made significant advancements in the last decade. Among the innovations are smart diagnostic tools and digital apps that expedite system diagnostics. These combined tools have made this installation, commissioning, and diagnostics of modern HVACR systems faster and more detailed than in the past. Smart diagnostic tools are transforming traditional HVACR practices by enhancing diagnostics, maintenance, and overall system efficiency. Today's digital tools and software allow the modern technician to explore the comprehensive approach of integrating temperature measurements, refrigerant pressures, airflow, and electrical measurements for total system performance assessment and diagnostic analysis in HVAC systems.

1. Measurement Integration

- **Temperature Measurements.** Monitor temperatures at key points to assess thermal performance and ensure efficient heat exchange.
- **Refrigerant Pressures.** Gauge pressures to verify refrigerant charge and system operation within specified ranges.
- **Airflow Rates.** Measure airflow to confirm proper distribution and volume, critical for system efficiency and comfort.
- **Electrical Measurements.** Assess electrical parameters such as voltage, current, and resistance to ensure safe and efficient operation of components.
-

2. Diagnostic Analysis

- **Calculating System Performance.** Utilize collected data to calculate parameters like total superheat, subcooling, and efficiency metrics.
- **Identifying Concerns.** Analyze deviations from expected values to diagnose issues such as airflow restrictions, refrigerant leaks, or electrical faults.
- **Assessment Tools.** Use diagnostic tools and charts to interpret measurements and identify potential performance deficiencies or operational concerns.



Efficiency Metrics. Smart diagnostic tools calculate system efficiency metrics, such as Seasonal Energy Efficiency Ratio 2 (SEER2) or Energy Efficiency Ratio (EER), providing insights into energy consumption and system performance. This helps in identifying opportunities for energy savings and optimization.

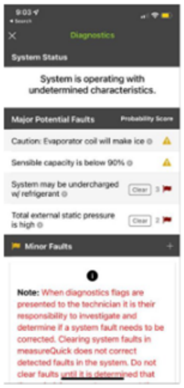
Remote Monitoring and Control. Some smart tools offer remote monitoring capabilities, allowing technicians to access system data and diagnostics from anywhere. This feature is particularly beneficial for monitoring HVAC systems in multiple locations or for providing remote support.

Interactive Troubleshooting Guides. Many smart apps include troubleshooting guides and step-by-step procedures for common HVAC issues. These guides can assist technicians in diagnosing problems systematically, ensuring comprehensive problem-solving.

Documentation and Reporting. Smart tools generate detailed reports and documentation automatically. These reports include performance data, diagnostic findings, recommended actions, and historical trends. Documentation aids in compliance with regulations, warranty requirements, and customer communication.

Integration with HVAC Systems. Some tools can integrate with HVAC system controls and management platforms, enabling seamless communication and control. This integration enhances system visibility and control, facilitating proactive maintenance and optimization.

Airflow is low



System Status

System is operating with undetermined characteristics.

Major Potential Faults	Probability Score
Caution: Evaporator coil will make ice	⚠
Sensible capacity is below 90%	⚠
System may be undercharged w/ refrigerant	Clear 3
Total external static pressure is high	Clear 2

Minor Faults

Note: When diagnostics flags are presented to the technician it is their responsibility to investigate and determine if a system fault needs to be corrected. Clearing system faults in measureQuick does not correct detected faults in the system. Do not clear faults until it is determined that

HIGH PERFORMANCE
HEAT PUMPS

CLIFTON BECK, CSME

In today's world, the push for energy efficiency and environmental sustainability has never been more urgent. One technology at the forefront of this movement is the heat pump. Opting for a heat pump offers dual benefits: enhancing home comfort and contributing to a healthier planet. Unlike traditional heating systems, heat pumps use less energy, emit fewer pollutants, and can integrate with renewable energy sources like solar and wind power. This makes them not only a smart choice for homeowners but also a crucial step toward a more sustainable future.

Choosing a heat pump is about more than just comfort; it's about making a responsible choice for the environment. These systems significantly reduce energy consumption and greenhouse gas emissions while helping stabilize the energy grid by working with clean, renewable sources. In regions with cold winters and hot summers, heat pumps provide efficient heating and cooling year-round, further enhancing their appeal as a versatile solution for both residential and commercial buildings.

In addition to their environmental benefits, heat pumps are gaining widespread adoption due to their efficiency. In states like New York, installations surged 37% from 2021 to 2022, with over 29,500 heat pump projects completed in 2022 alone. Nationally, heat pump installations have outpaced gas furnaces, signaling a shift in the heating and cooling industry toward more sustainable, high-performance options.

This book is designed to guide you through the next generation of high-performance heat pumps. Whether you're a homeowner, technician, or educator, understanding the advantages of these systems and how to properly install and maintain them is key to keeping pace with modern HVAC innovations.

Over the course of this book, we will explore various aspects of heat pumps, from their environmental impact to their role in energy diversification. By the end of this journey, you will not only have a deeper understanding of heat pumps but also be better equipped to make informed decisions or teach others about their growing importance in the world of sustainable energy.

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