SECOND EDITION

SYSTEM PERFORMANCE

MAXIMIZING ENERGY EFFICIENCY IN HEATING AND COOLING

AIRFLOW > CRITICAL CHARGE > PSYCHROMETRICS > COMBUSTION

HVAC Excellence

esco institute

SECOND EDITION

SYSTEM PERFORMANCE

Maximizing Energy Efficiency in Heating and Cooling

esco institute
Mount Prospect, IL
www.escogroup.org

PRINTING SECTOR UNION CWA LABEL CHICAGO, IL

ESCO Institute
PO Box 521
Mount Prospect Il 60056
Phone: 800-726-9696
Fax: 800-546-3726
Website: www.escogroup.org

ISBN-13 Print Edition: 978-1-930044-76-0
ISBN-10 Print Edition: 1-930044-76-3
ISBN-13 Ebook Edition: 978-1-930044-68-5

This book was written as a general guide. The authors and publisher have neither liability nor can they be responsible to any person or entity for any misunderstanding, misuse, or misapplication that would cause loss or damage of any kind, including loss of rights, material, or personal injury, alleged to be caused directly or indirectly by the information contained in this book.

Printed in the United States of America
7 6 5 4 3 2 1

Version 1.0 010126

Preface

In a time where sustainability and energy efficiency are at the forefront of the everchanging HVACR industry, field service technicians and professionals, more than ever, have the ability to make a significant difference in how the equipment we install, service and maintain affects our energy consumption and the overall health of our planet.

Heating, ventilation, air conditioning, and refrigeration systems account for **40–60% of the total energy consumed in U.S. homes and buildings**. And, while efficiency ratings such as **SEER2, EER2, COP, HSPF2, and AFUE** have been developed to provide minimum standards for efficiency and to guide consumers to more efficient products, these ratings alone do not guarantee superior, or even acceptable, system performance. **Even the most advanced technologies cannot overcome the negative effects of improper system installation or neglected maintenance protocols.** A system that is improperly charged or is operating with reduced airflow will never be able to deliver its intended capacity or its advertised efficiency. It is the technician who is responsible for ensuring that the manufacturer's intent and the system's real-world performance are in close alignment with each other.

This ***System Performance*** **training and certification series** was developed with one goal in mind; to aid technicians in enhancing their understanding of the many industry-accepted and embraced techniques and procedures used to both verify and optimize performance of HVAC systems. In this series, specific emphasis is placed on:

- **Airflow testing and verification**
- **Proper refrigerant charging and capacity testing**
- **Psychrometrics fundamentals**
- **Combustion efficiency**

To deliver comfort and system efficiency in a safe, professional, and efficient manner, technicians must understand how heat transfer, refrigerant behavior, and the properties of air interact with each other within the system. Mastering these fundamentals allows technicians to not only keep systems running, but also ensure that the equipment is performing in the most effective and efficient manner.

SYSTEM PERFORMANCE

Table of Contents

Table of Contents

Table of Contents

Abbreviations (Common Terminology)

Δh	Change in enthalpy (Btu/lb) of the air across the coil.
ΔT	Change in temperature (Delta T)
ΔW	Change in Absolute Humidity-represents the change in humidity ratio (grains of moisture per pound of air).
ACH	Air Changes per Hour
ADP	Apparatus Dewpoint Temperature
BPF	Bypass Factor
CFM	Airflow in Cubic Feet per Minute
CSA	Cross-Sectional Area of a duct, in ft^2
DB	Dry Bulb (°F)
EST	Evaporator Saturation Temperature
FPM	Air velocity in Feet Per Minute
ft^2	Square Feet or sq ft
MAT	Mixed Air Temperature
OA	Outside Air
OAT	Outside Air Temperature
Pi	π = 3.14 or (22/7)
PSI	Pound per Square Inch
Q_L	Latent heat in Btu/hr
Q_S	Sensible heat in Btu/hr
Q_T	Total heat in Btu/hr
RA	Return Air
RAT	Return Air Temperature
RPM	Revolutions Per Minute
RPS	Revolutions Per Second
SAT	Supply Air Temperature
SHR	Sensible Heat Ratio
SP	Static Pressure (AKA Sp or Ps)
TP	Total Pressure (AKA Tp or Pt)
TESP	Total External Static Pressure
VP	Velocity Pressure (AKA Vp or Pv)
WC	Inches of Water Column (##” WC)

Formulas - Airflow

Air Density = 0.075 lbs. per cu. ft. (ft^3)

Air Changes/hr (ACH) = (CFM×60) / Volume

Specific heat = 0.24 Btu

1 PSI = 27.7“ WC

1” WC = 249 Pa

1 Pa = 0.004“ WC

Sensible Heat Factor = Specific heat (0.24 Btu) × Density (0.075 lbs. /ft3 at sea level) × 60 minutes per hour = a factor of 1.08 (Formula: 0.24 x 0.075 x 60 = 1.08)

Sensible Heat Ratio SHR = $Q_S \div Q_T$

Sensible Heat Formula - Qs = 1.08 X CFM X ΔT

Latent Heat Formula – Q = 0.68 X CFM X ΔW

Total Heat – Qt = 4.5 X CFM X ΔW

Area of round duct = π x R^2

Equivalent area (Effective area) in (ft^2) = (H in. X W in.) ÷144 in^2

Recommended free area of return air grille = CFM of Return Air ÷ CFM/in^2

TP – SP = VP (AKA Pt = Ps + Pv or Tp = Sp + Vp)

Pressure total = Pressure static + Pressure velocity)

Velocity Pressure (VP) = Total Pressure (TP) – Static Pressure (Sp).

VF = 4005

Area x Velocity = CFM

FPM = √VP × VF

CFM = ft^2 × FPM

CFM = Equivalent Area × FPM

CFM =FPM × (AK factor or Net free area)

CFM = Sensible Load / (1.08 X ΔT)

CFM = Btu/hr Output ÷ (1.08 X ΔT)

BTU Output Btu/hr. X Equipment Efficiency % Btu/hr. X % = Output

Watts = Volts × Amps

Btu Output = Watts × 3.412

Supply Air – Return Air = Temperature Rise SA -RA = ΔT

Formulas - Psychrometrics

Q_T = 4.5 x CFM x Δh

Q_S = 1.08 x CFM x ΔT

Q_L = 0.68 x Cfm x ΔW

$Q_T = Q_S + Q_L$

SHR = $Q_S \div Q_T$

CFM = Air Velocity x CSA

1 ft^2 = 144 in^2

EST = ADP – 10°F

Specific Volume = 1 ÷ Density

Density = 1 ÷ Specific Volume

Density x Specific Volume = 1

Density of Standard Air = 0.075 lb/ft^3

Specific Volume of Standard Air = 13.33 ft^3/lb

BPF = (SAT DB – ADP) ÷ (RAT DB – ADP)

Diameter of Drive Pulley x RPM of Motor = Diameter of Driven Pulley x RPM of Blower

Percentage of OA = 100 x (MAT – RAT) ÷ (OAT – RAT)

MAT = (Percentage of OA x OAT) + (Percentage of RA x RAT)

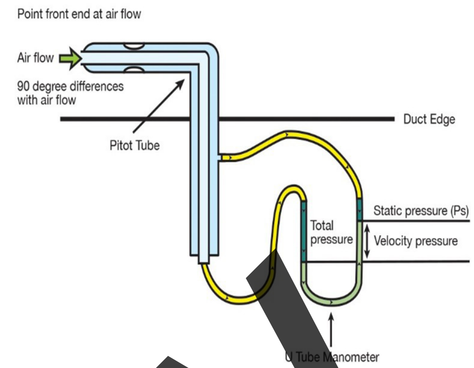
OAT = [MAT – (Percentage of RA x RAT)] ÷ Percentage of OA

RAT = [MAT – (Percentage of OA x OAT)] ÷ Percentage of RA

SHR Ranges

0.85 – 1.0	Precision Applications
0.65 – 0.80	Comfort Cooling
0.50 – 0.60	Dehumidification

Section 1
Airflow

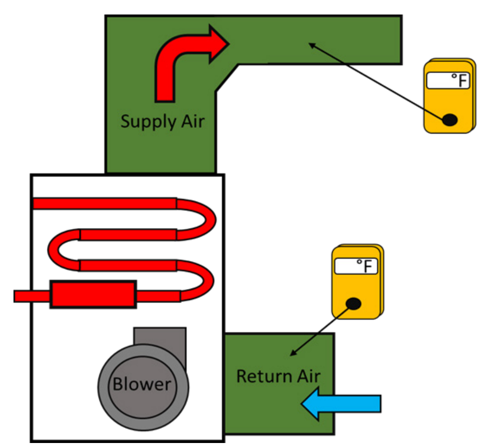


Airflow — General Objectives

Air properties and the measurement of air through an HVAC system are critical for comfort, charging, and system efficiency. Once airflow is understood, a technician will have a foundation of knowledge that supports many other aspects of HVACR systems.

Specific Objectives

1. Explain the calculations for sensible heat factor and sensible heat ratio.
2. Demonstrate the use of the sensible heat formula.
3. Identify different airflow measuring tools and demonstrate their use.
4. Describe factors which affect airflow such as velocity, square feet, static pressure and blower motor horsepower.
5. Determine the velocity of the air leaving a supply grille using an anemometer.
6. Determine the velocity of the air entering a return air filter grille using an anemometer.
7. Explain the air flow required to achieve a cooling system's rated capacity.
8. Explain the airflow required to achieve a heating system's rated capacity.
9. Develop critical thinking skills including analysis, evaluation, calculations, and use of measurement tools to evaluate a system's performance.



SYSTEM PERFORMANCE

Introduction

The air in a ducted heating and cooling system can go through many processes. It is circulated by a blower or fan, it can be heated or cooled, its moisture content can be altered through humidification or dehumidification, it can be filtered to remove contaminants, and its quality and quantity can be measured to verify proper system operation. The delivered conditioned air is used to maintain the desired indoor comfort and quality.

Air has weight, it extends miles above our heads, and its weight creates a pressure of 14.7 psi at sea level. Air holds heat, measured in British thermal units (Btu). Every cubic foot of air has the capacity to hold, increase, and decrease its heat content. Air also holds moisture. Each cubic foot of air can hold a certain amount of moisture, depending on the temperature and geographic location.

Airflow is one of the most over-looked functions of heating and cooling systems. Without proper airflow, system efficiency is compromised. A technician cannot properly charge an air conditioning system using the system superheat or subcooling methods when there is improper airflow. A heating system without proper airflow may operate at an unsafe temperature or short cycle, reducing the efficiency and life of the furnace.

The quantity of air flowing across the evaporator changes the sensible heat ratio of the air conditioning system, in turn changing the amount of moisture the system can remove. Nominal airflow for a central air conditioning system is 400 cubic feet per minute (CFM). Depending on ambient air conditions for a location, the quantity of air required across the evaporator for moisture removal could be as low as 325 CFM per ton. The airflow may be as high as 450 CFM for environments with low humidity. System efficiency, air filtering, sound levels, and most important of all, human comfort, are all influenced by system airflow.

Key Terms and Definitions

To understand air, air properties and air measurement, technicians should understand the following terms and know how and when to apply them when making calculations and/or recording measurements.

Air Velocity – The speed at which the air is moving, typically measured in feet per minute (FPM).

Air Volume – The amount of space occupied by air, usually measured in cubic feet (ft^3).

Average Air Flow – The acceptable range of air flow (in CFM) over the cooling coil to provide a temperature split necessary to remove moisture from the air

Constant Air Volume (CAV) – A system that provides a constant volume of air to all parts of the building. The supply air temperature may be varied to meet the needs of the space, either heated cooled.

Cubic Feet per Minute (CFM) – The volume of air, in cubic feet, that is moved or circulated in one minute.

Cubic foot – A unit of volume calculated using the formula: Length × Width × Height.

Delta T (ΔT) – Also known as the temperature split, refers to the difference between the air temperature entering the evaporator coil (return air) and the air temperature leaving the evaporator coil (supply air). It's a key indicator of how effectively the air conditioning system is removing sensible heat.

Density – Defined as mass per unit volume. Air density, like air pressure, decreases with increasing altitude. It also changes with variation in temperature or humidity.

Dry Bulb Temperature – A temperature measurement recorded using an ordinary thermometer.

Blower Performance Chart

Most manufacturers provide performance charts that indicate the volume of air the blower can supply based on the motor horsepower, the blower wheel's speed in revolutions per minute (RPM), and the expected static pressure. Blower performance charts are unique to each manufactured piece of equipment. There are no industry standard requirements.

For example, a furnace may have two performance charts: one for the furnace without additional components, and one indicating the CFM with additional components such as the matching evaporator coil. By measuring static pressure and using the blower performance chart for the equipment, the total volume of air can be estimated. If there is an evaporator coil in the system, this method is only accurate with a clean or like new coil. Additional consideration must be given to whether or not the chart is based on a wet or dry evaporator coil, when the coil is wet, moisture will add even more resistance to the airflow.

Before a duct system can be designed, the available static pressure, Total External Static Pressure (TESP) at times referred to as External Static Pressure (E.S.P.), from the blower performance chart, **Figure 1-10**, must be known. The available static pressure for most residential furnaces and air handlers is a maximum of 0.5 inches water column (WC) with a permanent split-capacitor (PSC) motor. Many newer furnaces can provide up to 1 inch of static pressure using an ECM or Electrically Commutated Motor.

Model	Speed	Volts		E.S.P (In. of H_2O)							
				0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
GPC1336M41* GPC1336M43*	LOW	230	CFM	1122	1078	1032	972	915	804	687	558
			WATTS	338	330	321	310	300	283	264	250
	MED	230	CFM	1387	1331	1264	1209	1119	1041	935	748
			WATTS	456	440	428	412	399	382	363	330
	HIGH	230	CFM	1521	1454	1388	1311	1230	1144	1055	939
			WATTS	534	521	510	490	477	461	442	420
GPC1348M41* GPC1348M43*	T1 (G)	230	CFM	1,140	1,395	1,360	1,310	1,265	1,235	1,190	1,130
			WATTS	275	285	295	315	325	335	345	355
	T2 / T3	230	CFM	1,795	1,765	1,715	1,695	1,650	1,600	1,500	1,375
			WATTS	475	490	505	520	530	535	510	475
	T4 / T5	230	CFM	1,860	1,820	1,785	1,745	1,700	1,625	1,515	1,395
			WATTS	515	530	545	565	570	550	535	485
GPC1360M41* GPC1360M43*	T1 (G)	230	CFM	1,755	1,720	1,685	1,645	1,615	1,570	1,530	1,465
			WATTS	420	435	455	460	475	490	500	500
	T2 / T3	230	CFM	1,850	1,820	1,775	1,735	1,705	1,675	1,610	1,495
			WATTS	480	500	515	525	535	555	545	520
	T4 / T5	230	CFM	2,180	2,125	2,050	1,975	1,875	1,800	1,655	1,530
			WATTS	770	755	725	700	675	640	575	540

Figure 1-10: *Blower performance chart. (Courtesy of Goodman Manufacturing)*

If the blower performance chart indicates that the blower can deliver the required CFM at 0.4" WC, the total pressure drop for the supply grilles, air filter, return grilles, supply duct, return duct, evaporator, and any accessories on the air side must not exceed 0.4"WC.

Note: Always read the notes that accompany a blower performance chart. The data shown may not include deductions for other components and accessories such as a wet coil, filter, heating elements, etc.

Air Turbulence in a Duct

Air traveling along the side walls of a duct, through elbows, plenums, mixing boxes, and flexible ducts will be disturbed by turning, change of direction, and dragging across uneven surfaces. When choosing a location for pitot tube placement, avoid areas of the duct where turbulence is likely to occur.

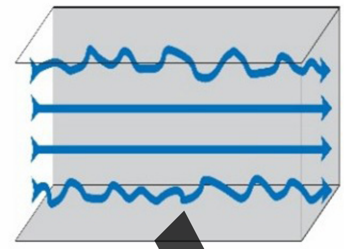


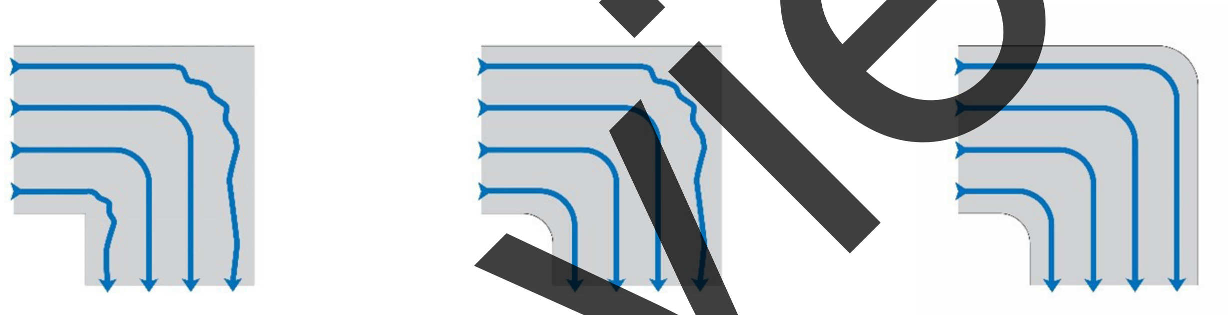
Figure 1-20: *Example of turbulence in a straight duct.*

Turbulence

As air moves, friction causes turbulence.

In straight duct the friction along the edge of the ducts causes the air to slow. This effect forms a curved cone with the air on the sides falling a little behind the air in the center of the duct. This is one of the reasons for taking multiple reading to determine the velocity pressure (VP). **Figure 1-20.**

The turbulence effect in elbows is more pronounced. Each type of elbow will have different effects. The smoother the curve the easier the air rounds the corner. Adding turning vanes makes the air flow smoother and more stable. **Figure 1-21A-C.**



A ***B*** ***C***

Figure 1-21A-C: *Examples of turbulence in a duct elbow with sharp curves (A), a duct elbow with a smooth and sharp curve (B), and a duct elbow with two smooth curves (C).*

Measuring the VP in turbulent air gives false and incorrect data. This can cause the airflow calculation for the measured area to be incorrect and cause occupants to be uncomfortable. Clean air movement is critical. Airflow measurements must be taken where air movement is not affected by turbulence.

Seeking clean air is necessary when making the VP measurements. Reading too close to a turn, split, reduction, or take off in the ducted system will cause distortions. The distance to "see" clean air depends on the design of the ducted system. Make sure the distance from the various fittings is enough to have non-turbulent air for measurements. Turning vanes are shown in **Figure 1-22.**

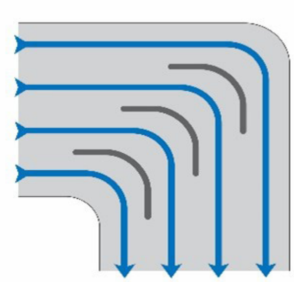


Figure 1-22: *Turning vanes shown in a duct elbow.*

Methods Used to Measure Pressure in a Round Duct

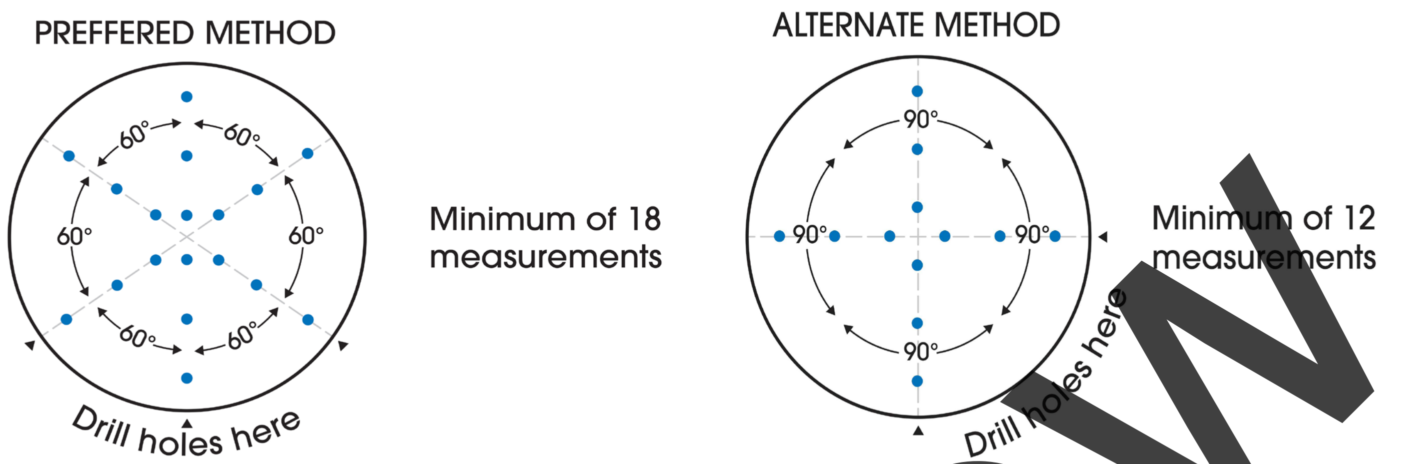


Figure 1-26: *Preferred and alternate methods of measuring pressure in a round duct.*

A pitot tube is placed into one of the drilled holes, then inserted to the depth determined by the distance provided in the table, **Figure 1-27**, below. (The table contains data based on percentage values of the distance across the duct. Multiply each number times the duct dimension in inches). The tube is turned to face into the airflow, and a pressure reading is taken.

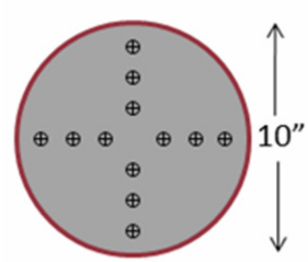
# of Measuring Points Per Diameter	*Log-Tchebycheff method* Position Relative to Inner Wall
6	0.032, 0.135, 0.321, 0.679, 0.865, 0.968
8	0.021, 0.117, 0.184, 0.345, 0.655, 0.816, 0.883, 0.979
10	0.019, 0.077, 0.153, 0.217, 0.361, 0.639, 0.783, 0.847, 0.923, 0.981

Figure 1-27: *This table contains data based on percentage values of the distance across the duct. Multiply each number times the duct dimension in inches.*

Example: A 10” round duct, using the alternate method, would have 6 measurements taken from the bottom hole and 6 measurements from the side hole for a total of 12 measurements. The insertion depth, from the inner side wall of the duct is shown in the row labeled 6.

To find the area for a round duct, use the formula: Area = $\pi \times R^2$ (radius squared).
(***Remember:*** *π is equal to 3.14 and R is the radius which is half the diameter)*

The area for a 10-inch duct is: Area in sq ft= $(\pi \times R^2) \div 144$
Area in sq ft = $(3.14 \times 5^2) \div 144$
Area in sq ft = $(3.14 \times 25) \div 144$
Area in sq. ft = $78.5 \div 144$
Area in sq ft = 0.545



Name: ______________________________ Date: ______________

Worksheet/Lab Project: Worksheet 2: Airflow Test Part 2.

Required Tools/Equipment: Pencil/Pen.

Required Resources: System Performance Textbook, Airflow Section.

Procedure: Circle the correct answer for each question.

1. What is the acceptable pressure drop across a clean air filter?
   A. 0.1 in. to 0.3” WC
   B. 0.1 in. to 0.4” WC
   C. 0.2 in. to 0.4” WC
   D. 0.1 in. to 0.5” WC

2. Which sheet metal elbow configuration produces the least airflow resistance and lowest turbulence?
   A. Square Throat/Square Heel
   B. Round Throat/Square Heel
   C. Square Throat/Round Heel
   D. Round Throat/Round Heel

3. How many downstream duct diameters must be allowed before taking a traverse reading?
   A. 1
   B. 3
   C. 5
   D. 7

4. When positioning a pitot tube for a duct traverse reading, which direction should the face be pointed?
   A. 90° away from the airflow
   B. At a 45° angle away from the airflow
   C. At a 45° angle into the airflow
   D. 90° into the face of the airflow

5. Using the alternate traverse method, how many measurement points are required for a rectangular duct with an 18” width?
   A. 5
   B. 6
   C. 7
   D. 8

Section 2
Critical Charging

Critical Charging — General Objectives

With the push for higher efficiency systems, the system charge is critical to proper operation and necessary to achieve the rated efficiency of the system. The critical charging method is like any other tool in the HVACR tool bag. Once it is understood it can be used to verify system performance as well as troubleshoot and diagnose faults.

Superheat Charging Chart

Condenser Entering Air Temperature	Indoor Wet-Bulb Temperature Entering the Evaporator													
	50	52	54	56	58	60	62	64	66	68	70	72	74	76
55°F	9	12	14	17	20	23	26	29	32	35	37	40	42	45
60°F	7	10	12	15	18	21	24	27	30	33	35	38	40	43
65°F		6	10	13	16	19	21	24	27	30	33	36	38	41
70°F			7	10	13	15	19	21	24	27	30	33	36	39
75°F				6	9	12	15	18	21	24	28	31	34	37
80°F					5	9	11	15	18	21	25	28	31	35
85°F							9	11	15	19	22	26	30	33
90°F							6	9	13	16	20	24	27	31
95°F								6	10	14	18	22	25	29
100°F									8	12	15	20	23	27
105°F									5	9	13	17	22	26
110°F										6	11	15	20	25
115°F					Superheat tolerance ± 5°F						8	14	18	23
	To increase superheat remove refrigerant.							To decrease superheat add refrigerant.						

Specific Objectives

1. Identify the different leak detection methods.
2. Discuss the preliminary required checks and troubleshooting for system charging.
3. Describe how to calculate temperature split or Delta T.
4. Describe how to calculate total system refrigerant charge.
5. Identify and describe the use of various charging methods including:
   A. Charge by Weight
   B. Manufacturer's Charging Charts
   C. System Superheat
   D. Subcooling
6. Explain how to charge blended refrigerants.
7. Explain how to properly evacuate and dehydrate a system.
8. Discuss liquid and suction line sizes and factors that affect them.

SYSTEM PERFORMANCE

Some of the most common sources of a leak are:
- A leaking tube joint (braze, solder, flare, press, or compression fitting)
- Loose fittings or caps (due to vibration)
- Improperly seated service valves (leaky valves or Schraeder pins)

An air conditioning system that has a leak must have the refrigerant recovered prior to repair, following EPA requirements.

NOTE: A leaking system should be repaired before adding any refrigerant.

Calculating the Indoor Air Temperature Split

The industry standard for airflow across the evaporator is 400 cubic feet per minute (CFM), per ton of cooling. In areas with a high latent heat load, or high humidity climates, slightly lower airflow (325-350 CFM) can be used across the evaporator for additional humidity removal. In areas with a high sensible heat load, slightly higher airflow (425-450 CFM) can be used to satisfy the conditioned space requirements. Always refer to the manufacturer's literature for airflow recommendations for the equipment being used. On a system that is properly installed, has the correct charge, and is clean, the temperature split (difference in temperature between the supply and return ducts) should be between 16°F - 22°F, depending on the system's efficiency and the latent load on the system. After a system has been operating for a minimum of fifteen to twenty minutes, record the difference between the air temperature entering the return grill and the air temperature coming out of the supply registers. The difference between these temperatures is the temperature split or Delta T.

Mathematical Conversions

Before covering the various charging methods, it is important to understand how to convert between various units of measurement. Manufacturers list the weight of refrigerant charge on the data plate or in the literature, in several different units of measure (pounds, ounces, decimal pounds, fractions, etc.). Technicians must be able to convert from one unit to another (fractions of a pound to ounces. etc.). The following are a few weight equivalents for converting from one unit to another.

1 pound = 16 oz — 1 ounce = 0.0625 pounds
1 pound = 454 grams — 1 pound = 0.454 kilograms

Examples:

Convert 5.5 lbs 0.5 lb x 16 (Ounces per lb) = 8 oz 5 lb x 16 (oz/lb) = 80 oz 80 oz + 8 oz = 88 oz	**Convert 4.5 lbs to oz** 4.5 x 16 = 72 oz **Convert 32 oz to lbs** 32 oz x 0.0625 = 2 lbs
Convert 3.8 lbs 0.8 lb x 16 (oz/lb) = 12.8 oz 3 lbs x 16 (oz/lb) = 48 oz 48 oz + 8 oz = 60.8 oz equivalent 3 lbs 12.8 oz or 60.8 oz	**Convert 3 lbs to kg** 3 lbs x 0.454 = 1.362 kg **Convert 3 lbs to grams** 3 x 454 = 1362 grams

System Superheat

When evaluating the performance or charge of a system, one task often performed by the HVACR service technician is calculating system superheat. A refrigerant absorbs heat in the evaporator and rejects it in the condenser. Superheat is the amount of heat absorbed above the boiling point, after all liquid has boiled to a vapor. All systems should have some superheat to ensure that liquid refrigerant does not leave the evaporator and make its way to the compressor. System superheat is the heat added to the refrigerant vapor inside the evaporator all the way back to the compressor and varies as operating conditions change. When the outdoor temperature is low, the system superheat can be as high as 40°F. When the outdoor temperature is high, the system superheat can be as low as 5°F. There is superheated vapor in several places in the system: the evaporator outlet, suction line, compressor, discharge line, and the beginning of the condenser. System superheat must not be confused with the evaporator superheat maintained by the thermostatic expansion valve.

The system superheat method is used to charge partially charged systems or to finish charging a split system after installation. It is calculated to ensure performance of a split system air conditioner or heat pump if it has a fixed metering device, such as a capillary tube or fixed orifice. For a heat pump system, superheat charging can only be properly performed when the system is operating in cooling mode and the outdoor temperature is above 65°F degrees.

Measuring System Superheat

System superheat is a measurement of temperature increase of the saturated vapor entering the compressor. Suction line temperature is taken at the outdoor unit on or near the suction access valve. The formula for system superheat calculations is: **vapor line temperature – suction saturation temperature = superheat**. System superheat is used by the technician to check the charge at the outdoor unit. Low superheat is typically caused by an overcharge; refrigerant must be removed. If superheat is high, the system is typically undercharged, refrigerant must be added based on the manufacturer's recommendations. Most manufacturers recommend the superheat be within (+) or (-) 5°F of published charging data, **Figure 2-9**. **Note:** All the system faults must be corrected, the coils cleaned, and the proper airflow verified before adjusting the charge.

Superheat Charging Chart Indoor Wet-Bulb Temperature Entering the Evaporator															
		50	52	54	56	58	60	62	64	66	68	70	72	74	76
Condenser Entering Air Temperature	55°F	9	12	14	17	20	23	26	29	32	35	37	40	42	45
	60°F	7	10	12	15	18	21	24	27	30	33	35	38	40	43
	65°F		6	10	13	16	19	21	24	27	30	33	36	38	41
	70°F			7	10	13	15	19	21	24	27	30	33	36	39
	75°F				6	9	12	15	18	21	24	28	31	34	37
	80°F					5	9	11	15	18	21	25	28	31	35
	85°F							9	11	15	19	22	26	30	33
	90°F							6	9	13	16	20	24	27	31
	95°F								6	10	14	18	22	25	29
	100°F									8	12	15	20	23	27
	105°F									5	9	13	17	22	26
	110°F										6	11	15	20	25
	115°F					Superheat tolerance ± 5°F						8	14	18	23
		To increase superheat remove refrigerant.							To decrease superheat add refrigerant.						

Figure 2-9: System superheat charging chart.

Evacuation/Dehydration: Residential Systems

Air-conditioning and refrigeration systems are designed to operate with only refrigerant and oil circulating through the system. If air is present in the system, it will not operate efficiently and its life span will be greatly reduced as well. Air contains oxygen, nitrogen, hydrogen, and water vapor, all of which are harmful to the refrigerant system. The other gases from the atmosphere are non-condensables and may cause chemical reactions, which can produce acids in the system, leading to deterioration of components. Problems such as copper plating of the compressor bearings and motor winding insulation breakdown may occur.

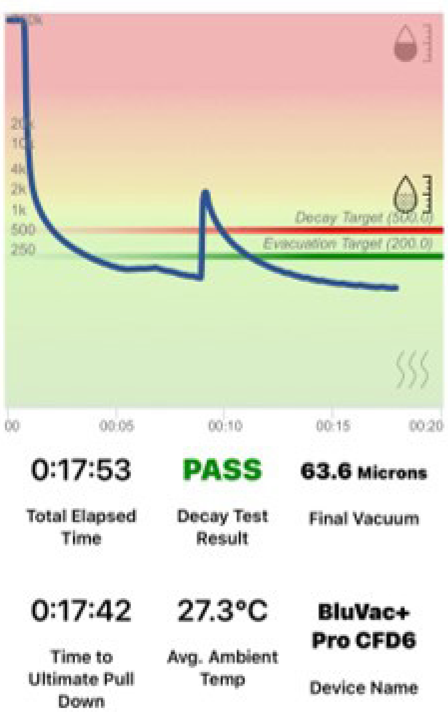


Figure 2-15: Vacuum decay test results.

Refrigeration system evacuation is a combination of two processes: degassing and dehydration. Degassing is the process of removing air and other non-condensables from the system. The removal of moisture from a system is called dehydration. The level of system evacuation can be measured in inches of mercury (in Hg) or microns. HVACR systems should be evacuated until a deep vacuum (typically below 500 microns) is reached. The first stage of the evacuation process, degassing, removes air and other non-condensables as the pressure inside of the system is lowered by the vacuum pump. As the vacuum pressure in the system approaches about 5000 microns, the degassing stage is complete, and the dehydration stage begins.

A micron is the smallest increment of measurement used in the vacuum process. One inch of vacuum is equal to 25,400 microns. Atmospheric pressure, 0 PSIG, is equal to 760,000 microns. Vacuum pumps must be able to reduce the system pressure from 760,000 microns to 500 microns or less. (Refer to manufacturer's recommendations.) The system must be able hold the pressure when isolated from the vacuum pump, known as a decay test, **Figure 2-15**. The micron gauge should be connected to the system as far away from the vacuum pump connections as possible and never in line with the vacuum pump.

An evacuation of the system is required every time an empty system is to be charged or anytime the technician has recovered the refrigerant for repairs. Proper evacuation or deep vacuums cannot be measured without a micron gauge, **Figure 2-16**.

Figure 2-16: Digital micron gauge.

Most often, non-condensables are introduced during installation, or system service. The introduction of non-condensables into a system must be prevented. Tests have shown a 7.5% or higher loss in efficiency when even small amounts of non-condensable gases are inside the system.

Line Sizing

When verifying that a system is properly charged to operate at peak efficiency, line set length and size are critical. Refrigerant lines are often improperly sized, which can greatly reduce system capacity. The suction line is the line with the greatest effect on the system. The suction line should be sized to prevent a pressure drop that will cause more than a two-degree change in saturation temperature. The amount of allowable pressure drop depends on the type of refrigerant and the evaporator temperature.

Example:

Evaporator Temperature	Saturated Pressure	
	R-22	R-32
45°F	76 psig	133 psig
- 2°F		
43°F	73.0 psig	128 psig
Maximum Allowable Pressure Drop	**3 psig**	**5 psig**

When trying to determine the proper piping diameter, it is not just length that must be considered. Each bend in the line adds to the overall pressure drop, but not all bends or turns have the same pressure drop. The line may be bent by hand, with a bending spring, or mechanical bender, and can be a short or long radius elbow. All of these methods increase the pressure drop and can affect overall system performance.

The manufacturer's literature will list recommended line sizing based on normal installations. It is up to the installer to make sure lines are sized to compensate for length, bends, and elbows used at the time of installation. There will be an approximate two-percent drop in capacity for a 75-foot line set and a four-percent drop for a 150-foot line set. The only way to check the actual pressure drop in a system is to tap into the lines and take a pressure measurement at the beginning and end of the refrigerant line.

In addition to affecting system capacity, improper line sizing can shorten the life span of a system and create poor oil return to the compressor. The refrigerant velocity required to move oil through a system is different for each type of line. This required velocity is determined by whether the refrigerant is in a vapor or liquid state, and whether the line is vertical or horizontal.

To ensure proper oil return, minimum velocity should be 800 FPM (feet per minute) in a horizontal suction line and 1000 FPM in a vertical line. Velocity should not exceed 4000 FPM. Liquid line velocity must be 300 FPM or less to prevent noise, surface ware, and valve ware.

NOTE: Remember to follow manufacturer's requirements for each system.

When installing high-efficiency systems, it is vital to use the manufacturers' piping requirements. On two-stage or variable-speed systems, refrigerant velocity changes with system capacity. Depending on the evaporator's location in relation to the condensing unit, or if the system is operating at lower capacity, a higher-than-normal pressure drop may be required to achieve proper oil return. If the condensing unit is much higher than the evaporator, commercial piping practices may be required. In some cases, a trap and suction line riser are necessary to ensure oil return.

Name: ____________________________________ Date: _________________

Worksheet/Lab Project: Worksheet 1: Critical Charge Part 1.
Required Tools/Equipment: Pen/Pencil.
Required Resources: System Performance Textbook, Critical Charge Section.
Procedure: Circle the correct answer for each question.

1. What is one major effect of a slight overcharge or undercharge in a residential A/C system?
   A. It will have no noticeable effect.
   B. It can cause compressor overheating.
   C. It can result in significant loss of cooling capacity and efficiency.
   D. It only affects heating performance.

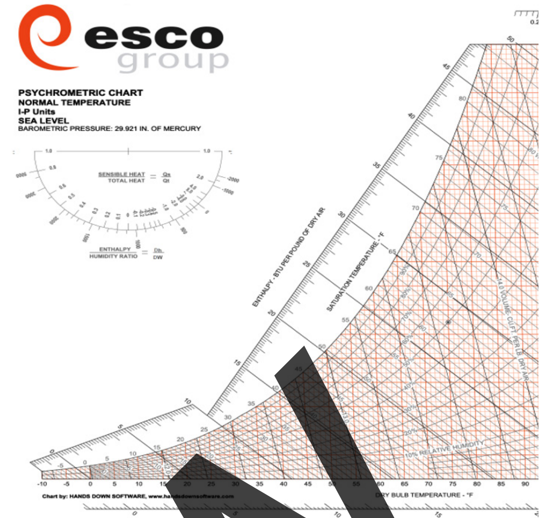
2. What is the industry's "ABC" best practice before charging a system?
   A. Always Balance Coils
   B. Airflow Before Charging
   C. Avoid Bypassing Controls
   D. Add Base Charge

3. What does frost on an air conditioner's suction line usually indicate?
   A. Proper charge
   B. Low refrigerant charge or restricted airflow
   C. Dirty filter drier
   D. Overcharge of refrigerant

4. What is the typical sensitivity of most electronic refrigerant leak detectors?
   A. 1 oz/year
   B. 0.15 oz/year
   C. 5 oz/year
   D. 10 oz/year

5. What is the normal temperature split (ΔT) for a properly charged and operating A/C system?
   A. 8°F – 12°F
   B. 10°F – 15°F
   C. 16°F – 22°F
   D. 25°F – 30°F

Section 3
Psychrometrics

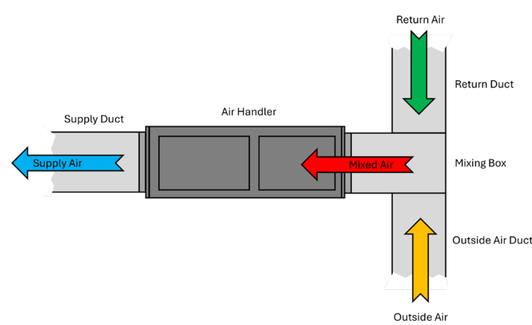


Psychrometrics — General Objectives

Psychrometrics has the potential to become a powerful tool in the HVAC industry professional's arsenal. Once mastered, the knowledge of air and its properties can be effectively applied to the design, performance, troubleshooting and diagnostics of air conditioning and air distribution systems.

Specific Objectives

1. Define psychrometrics.
2. Explain the thermodynamic properties of air and water vapor.
3. Explain the water vapor cycle in the earth's atmosphere.
4. Describe standard air volume and density.
5. Identify what each line on a psychrometric chart represents.
6. Explain the concept of the comfort zone.
7. Explain how temperature and relative humidity affect human comfort.
8. Demonstrate the ability to plot points on the psychrometric chart and evaluate the data.
9. Describe the eight processes of air conditioning and how to plot each one on a psychrometric chart.
10. Define sensible heat, latent heat and total heat.
11. Perform system calculations using the sensible heat, latent heat, and total heat formulas.
12. Define sensible heat ratio.
13. Define mixed air and perform mixed air calculations.
14. Develop critical thinking skills including analysis, evaluation, calculations, and the use of computer technology.



SYSTEM PERFORMANCE

Understanding the Lines on the Psychrometric Chart

Although the psychrometric chart may look intimidating at first, there are only seven primary lines and sets of lines on the chart that you need to be concerned with. Each of them will be discussed in detail as we progress through this section. These lines are:

- The vertical lines that represent lines of constant dry-bulb temperature.
- The gently sloped lines (from bottom right to upper left) that represent lines of constant wet-bulb temperature and lines of constant enthalpy, or total heat.
- The upward curved lines that represent lines of constant relative humidity.
- The left curved boundary of the chart represents 100% relative humidity.
- The bottom horizontal edge of the chart represents 0% relative humidity.
- The horizontal lines on the chart that represent lines of constant dew point temperature and constant absolute humidity.
- The steeply sloped lines (from bottom right to upper left) that represent lines of constant specific volume.

A graphical representation of these psychrometric chart lines is provided in **Figure 3-5**.

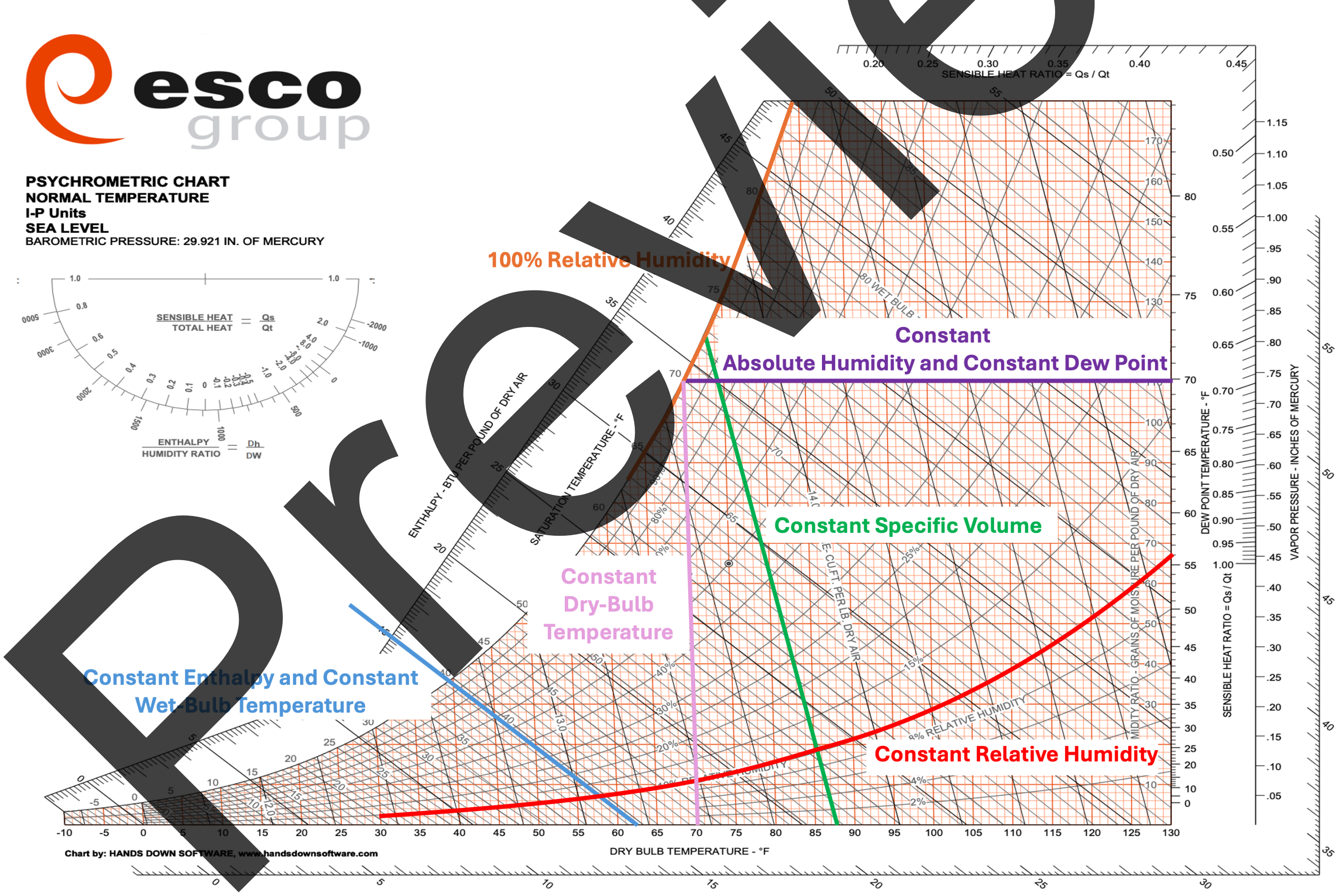


Figure 3-5: Important lines of a psychrometric chart.

the blue shaded region in **Figure 3-20**, while the comfort zone for heating is indicated by the green shaded region in **Figure 3-21**. The closer the air conditions are to the center of the comfort zone, the more likely an individual is to be comfortable. It is important to note that the cooling and heating comfort zones are not the same, although there are certain sets of air conditions that can be found in both zones. **Figure 3-22** shows how these two comfort zones relate to each other and how, under certain circumstances, they overlap.

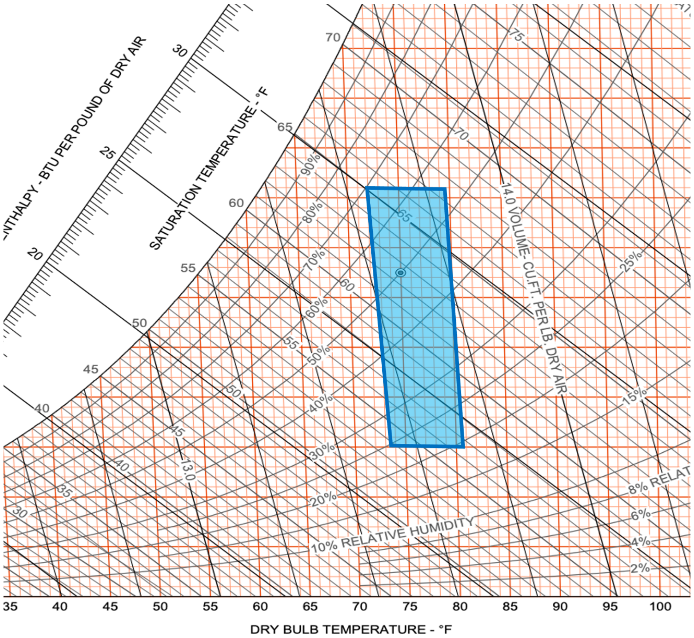


Figure 3-20: *The cooling comfort zone is shown by the blue shaded region.*

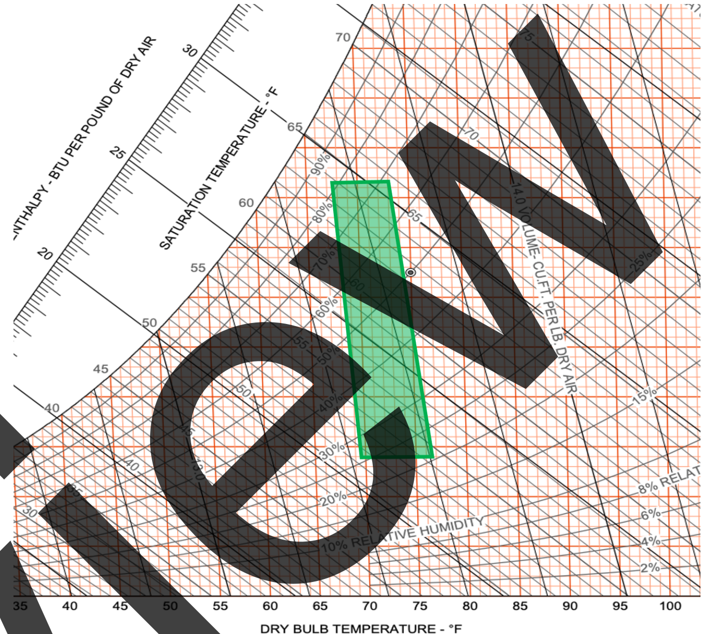


Figure 3-21: *The heating comfort zone is shown by the green shaded region.*

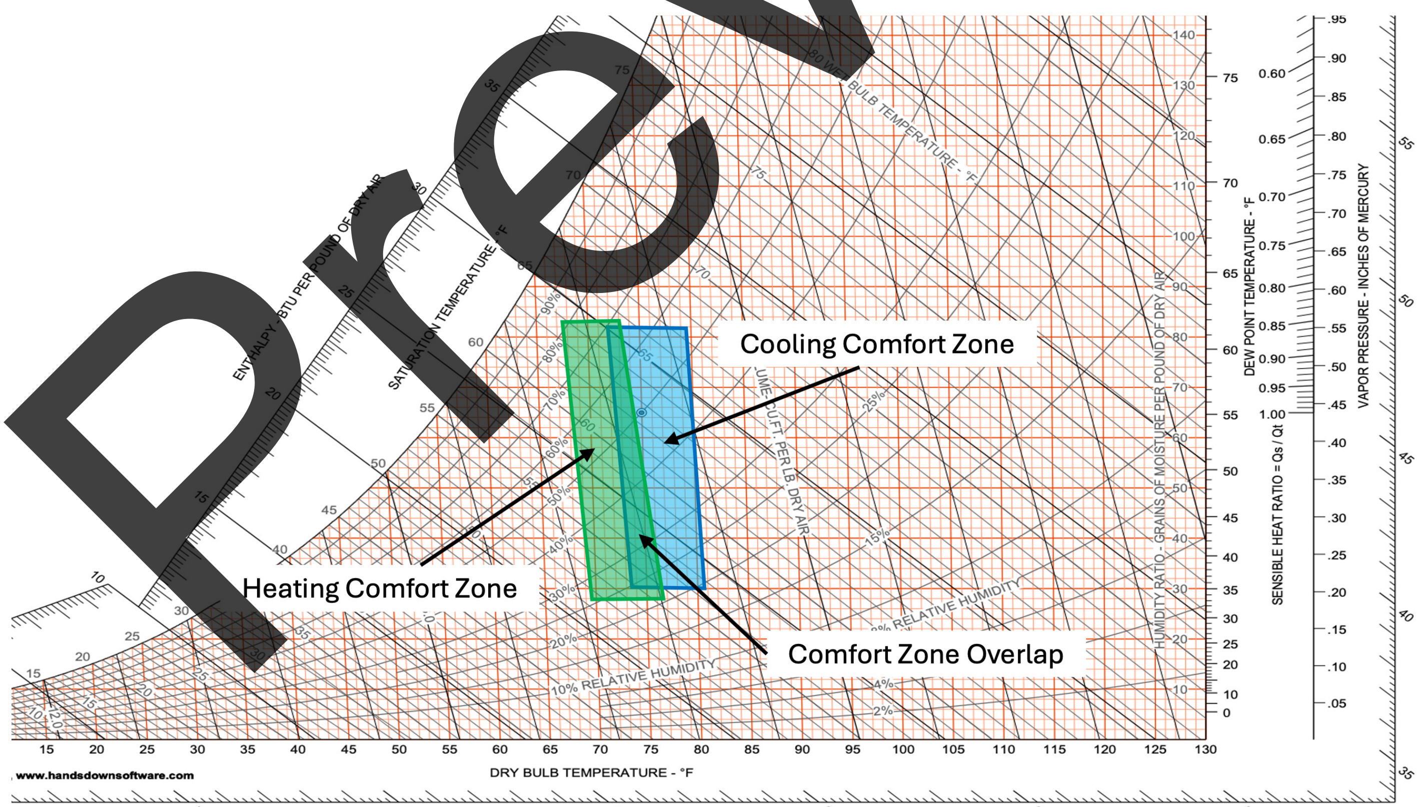


Figure 3-22: *The heating and cooling comfort zones overlap in the shaded area, representing conditions where both zones apply.*

Sensible Heat Calculations

The amount of sensible heat that is transferred during a process can be calculated using the sensible heat formula:

$$Q_S = 1.08 \times CFM \times \Delta T$$

where Q_S represents the quantity of sensible heat energy, in Btu/hr
1.08 is a conversion constant
CFM represents the process's airflow rate, expressed in cubic feet per minute
ΔT is the change in temperature between the return air and the supply air

Latent Heat Calculations

The amount of latent heat that is transferred during a process can be calculated using the sensible heat formula:

$$Q_L = 0.68 \times CFM \times \Delta W$$

where Q_L represents the quantity of latent heat energy, in Btu/hr
0.68 is a conversion constant
CFM represents the process's airflow rate, expressed in cubic feet per minute
ΔW is the change in absolute humidity between the return air and the supply air

Total Heat Calculations

The total amount of heat energy, both latent and sensible, that is transferred during a process can be calculated using the total heat formula:

$$Q_T = 4.5 \times CFM \times \Delta h$$

where Q_T represents the quantity of heat energy, in Btu/hr
4.5 is a conversion constant
CFM represents the process's airflow rate, expressed in cubic feet per minute
Δh is the change in enthalpy between the return air and the supply air

The change in enthalpy, Δh, accounts for both the latent heat energy transferred as well as the amount of sensible heat transferred. Consider once again the process shown in Figures 27 and 28. It was determined that the Δh for this process was 6.2 Btu/lb. But how much enthalpy was associated with the sensible heat transfer and how much was associated with the latent heat transfer? These values can be easily obtained from the process triangle. Here's how. By creating the process triangle and identifying the point where the horizontal line from point B and the vertical line from point A cross, a new point, point C, is identified, **Figure 3-30**.

Sensible Heat Ratio: Example 2

Using the graphical method, determine the SHR for the set of system conditions provided in Example 1. Then, compare this result to the value obtained by using the SHR formula.

To obtain the SHR for the set of system conditions provided, a line is drawn parallel to the process line that extends through the SHR scale, **Figure 3-36**. From this line, the SHR (0.52) can be read directly from the SHR scale. The value obtained using both methods is the same.

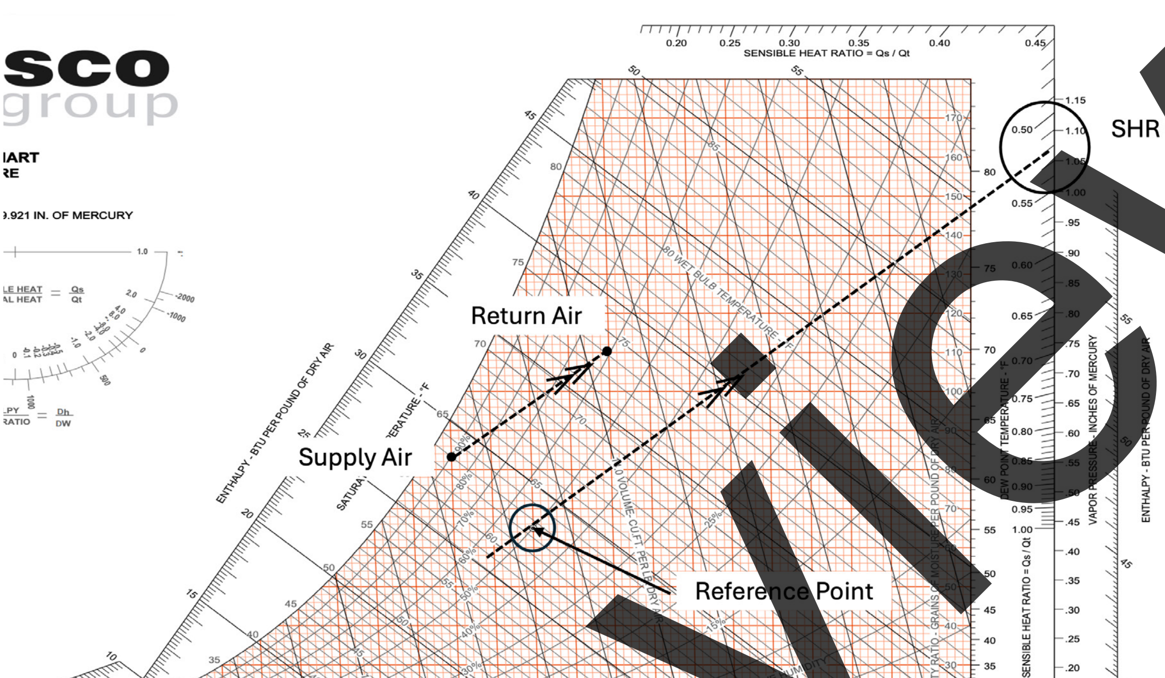


Figure 3-36: *Using the graphical method, the sensible heat ratio (SHR) is determined as 0.52, matching the value calculated with the SHR formula.*

Mixed Air Systems

Many air-conditioning systems, such as the ones referenced up to this point in our discussion of psychrometrics, have two airstreams: the return airstream, RA, and the supply airstream, SA. However, there is a large number of systems that bring outside air into the conditioned space and have four airstreams. In addition to the return airstream and the supply airstream, these systems have an outside airstream, OA, and a mixed airstream, MA, **Figure 3-37**. The outside airstream and return airstream are combined in what is referred to as the mixing box, which is connected to the air handler on its return air side. As a result, the two airstreams that interact directly with the air handler are the mixed airstream and the supply airstream.

Although it might seem counterproductive to bring hot, potentially humid, outside air into the occupied space in the hot, summer months, or to bring cold outside air into the occupied space in the cold winter months, there are logical reasons for doing so. In order to maintain desirable levels of oxygen in the space and to satisfy ventilation requirements for systems and structures, outside air must be introduced to the space.

The amount of outside air that is brought into a structure is determined by a number of factors that include the interior volume of the structure, the number of people occupying the structure, and the activities the structure's occupants are engaging in. The calculations that determine the actual amount of outside air that is to be brought into a structure are beyond the scope of this work. Instead, we will provide formulas that can be used to calculate the conditions of the mixed air once the proper amount of outside air has been introduced to the system.

Note: Any of the formulas presented in this material can be manipulated depending on the known air conditions and the condition that must be determined.

The relative humidity of a system's mixed airstream can be closely approximated using the same formulas that were previously provided. However, instead of using dry-bulb temperatures, the relative humidity values are used. It is important to note that, since the lines of constant relative humidity are not straight, the relationships that exist are not linear, so the calculation results will have small errors. The good news is that these errors are not significant to the HVAC service technician, although they are likely to be problematic for critical engineering calculations.

Mixed Air Calculations: Example 5

Calculate the relative humidity of the mixed air for a system operating with the following conditions:

- Percentage of Return air: 90%
- Percentage of Outside air: 10%
- Relative humidity of Return air: 50%
- Relative humidity of Outside air: 80%

For this calculation, we will start with the formula for the dry-bulb temperature of the mixed air and modify it to calculate the approximate relative humidity of the mixed air:

$$MA_{\text{DRY-BULB}} = (\text{\% of Return Air} \times RA_{\text{DRY-BULB}}) + (\text{\% of Outside Air} \times OA_{\text{DRY-BULB}})$$

$$MA_{\text{RELATIVE HUMIDITY}} = (\text{\% of Return Air} \times RA_{\text{RELATIVE HUMIDITY}}) + (\text{\% of Outside Air} \times OA_{\text{RELATIVE HUMIDITY}})$$

We can then substitute the known values for the percentage of the outside air and its relative humidity, and the percentage of the return air and its relative humidity:

$$MA_{\text{RELATIVE HUMIDITY}} = (\text{\% of Return Air} \times RA_{\text{RELATIVE HUMIDITY}}) + (\text{\% of Outside Air} \times OA_{\text{RELATIVE HUMIDITY}})$$

$$MA_{\text{RELATIVE HUMIDITY}} = (0.90 \times 50) + (0.10 \times 80)$$

$$MA_{\text{RELATIVE HUMIDITY}} = 45 + 8$$

$$MA_{\text{RELATIVE HUMIDITY}} = 53\%$$

Once again, it should be noted that this value is a close approximation, but will not be exact.

Name: ____________________________________ Date: _________________

Worksheet/Lab Project: Worksheet 8: Use a Psychrometer, Psychrometric Chart, and Formulas to Verify Capacity of an A/C unit.

Required Tools: Psychrometer (Sling or Digital), charts, and Tools Required to Gain Access to Plenum Supply and Return Air.

Required Tools/Equipment: Unit Selected by Instructor: properly charged, undercharged and overcharged.

Required Resources: System Performance Textbook, Psychrometrics Section.

Safety Precautions: Psychrometer is a delicate instrument and care should be used not to damage the instrument or hit another object or person.

Procedure: Review the use of psychrometer from manufacturer's literature. Use the psychrometer to obtain wet and dry-bulb measurements from return and supply air. Record your measurements on the chart below. Measure or obtain CFM using manufacturer's literature.

Lab Station No	
Equipment Make	
Equipment Model	
Equipment rated Btu/hr	
Equipment CFM	

Location	Dry Bulb	Wet Bulb	Relative Humidity
Return Air			
Supply Air			

Student Notes:

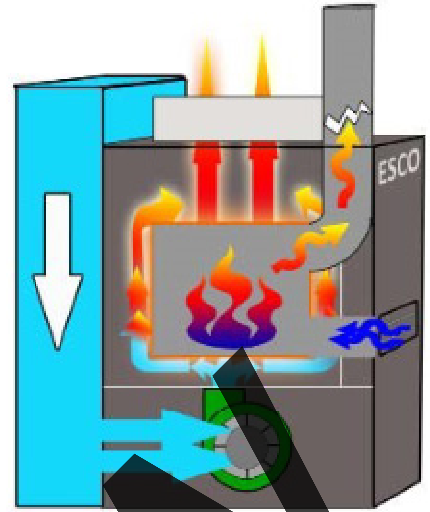
Sensible Heat		
Latent Heat		
Total Heat		

1. Is the system operating within manufacturer's specifications?

2. Is the system airflow within manufacturer's specifications?

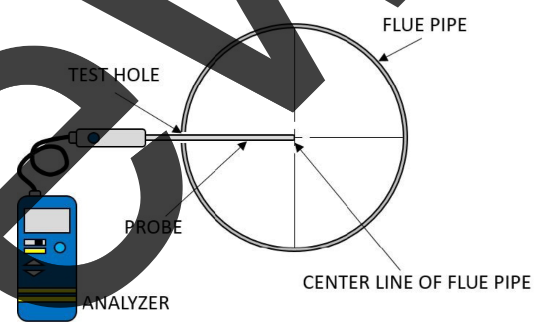
3. If not, is it over or under charged?

Section 4
Combustion



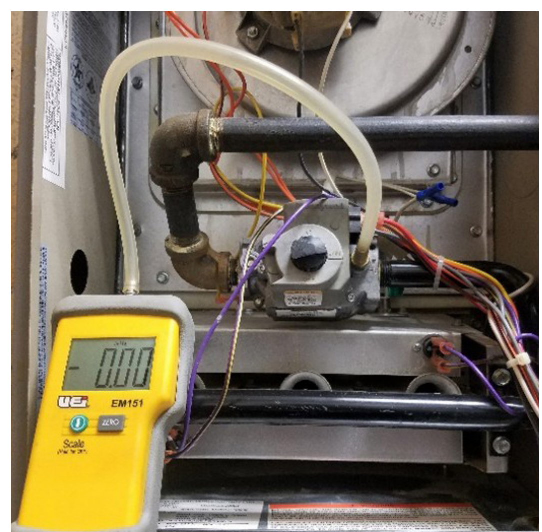
Combustion — General Objectives

This section will familiarize the readers with combustion basics as well as how to properly perform a combustion analysis. This section will also provide readers with an understanding of the steps required to calculate combustion efficiency.



Specific Objectives

1. Define basic combustion and identify the fuels used in the process.
2. Discuss the differences between perfect, complete, and incomplete combustion.
3. Describe different types of draft and how they relate to combustion.
4. Understand and utilize the stoichiometric chart to analyze the combustion process.
5. Explain the difference in efficiency between mid- and high-efficiency furnaces.
6. Describe and identify the combustion testing procedures including probe insertion depth, probe hole locations and hole sealing methods.
7. Describe and explain manifold gas pressure testing and adjustment.
8. Discuss how manifold gas pressure can affect appliance efficiency.
9. Define and explain temperature rise and the temperature rise testing procedures.
10. Explain the process of timing a gas meter to calculate the total Btu input to an appliance.
11. Calculate orifice deration based on elevation.



SYSTEM PERFORMANCE

Perfect Combustion

Perfect combustion refers to using the fuel and oxygen in exact proportions with nothing left over once the combustion process has been completed. Technically speaking, perfect combustion is referred to as Stoichiometric combustion, which is the burning of fuel with the exact amount of oxygen (O_2) required to change all the carbon and hydrogen atoms contained in the fuel into carbon dioxide (CO_2) and water (H_2O) vapor, without producing any carbon monoxide, **Figure 4-6**. Chemically speaking, the balanced reaction for the perfect combustion of methane (CH_4) would look like this:

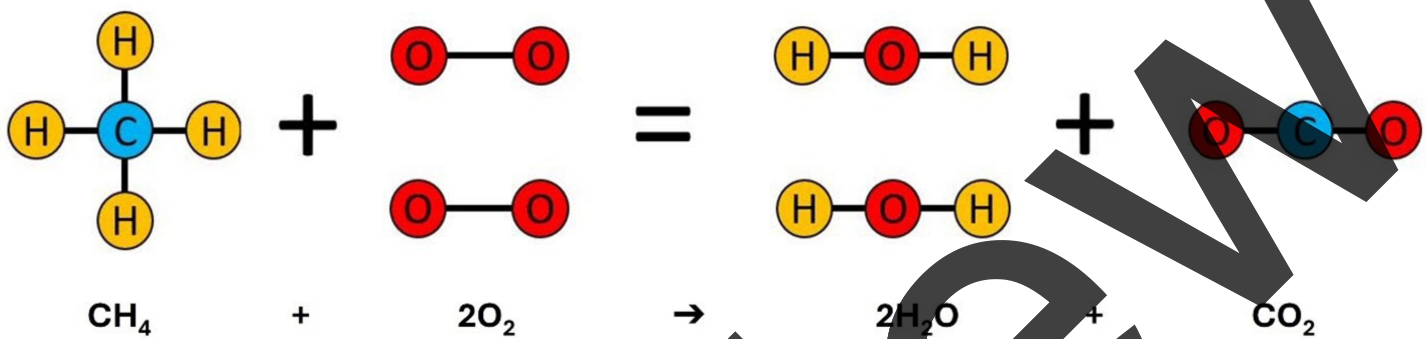


Figure 4-6: A visual representation of perfect combustion of Methane.

This relationship means that for every unit of methane gas that is to be burned, two units of oxygen will be required for perfect combustion. If 1 cubic foot of natural gas is to be burned, 2 cubic feet of oxygen will be needed. However, each cubic foot of air only contains about 20% oxygen, **Figure 4-7**. Therefore, for each cubic foot of oxygen needed, about 5 cubic feet of air must be supplied to the combustion process. For perfect combustion, each cubic foot of natural gas will require approximately 10 cubic feet of air.

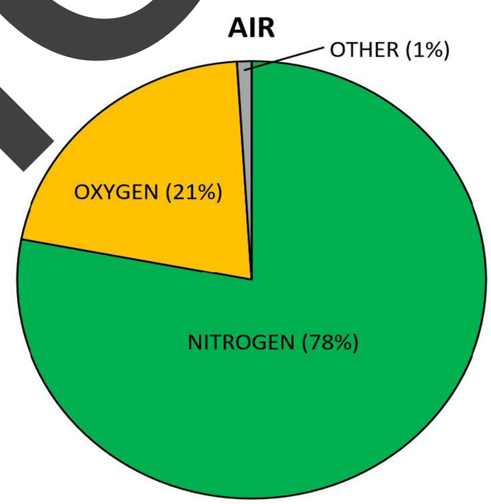


Figure 4-7: Elemental makeup of air.

Complete Combustion

Complete combustion refers to the burning of fuel, while still having some oxygen left over at the end of the process, **Figure 4-8**. This differs from perfect combustion, where there was no oxygen left over. In the practical world, perfect combustion does not occur since there are too many variables that affect the combustion process. Excess air is added to the combustion process to ensure that all of the fuel is combusted. 50% is the acceptable amount of excess air for most applications, however, additional air may be required for dilution to prevent condensation of flue gases.

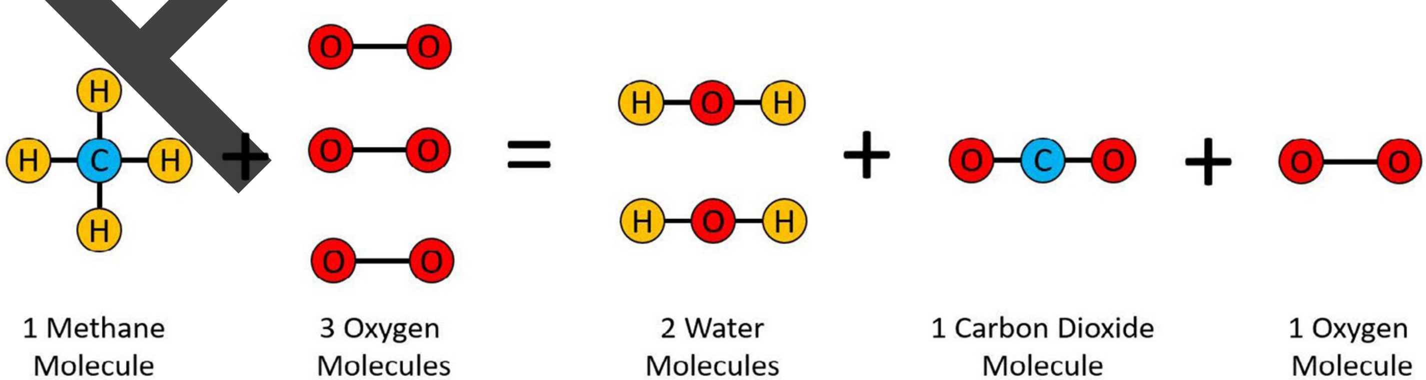


Figure 4-8: A visual representation of complete combustion of Methane.

Chart Description

The Theoretical Air Curve of Natural Gas (Stoichiometric chart) shows the O_2 , CO_2 , and excess air relationship, **Figure 4-11**. The following information can be used to interpret the chart.

- Vertical Axis (left side) of the chart is the percentage of oxygen (O_2) and CO_2 in flue gas after combustion has taken place.
- The red line is the percentage of CO_2 in flue gas after combustion. The percentage of CO_2 in the flue gas increases as the percentage of O_2 decreases.
- The blue line is the percentage of O_2 in flue gas after combustion. Combustion starts with 20.9% O_2 and decreases as it is used to form CO_2 and H_2O.
- Horizontal axis (bottom line) is the percentage of excess air introduced to combustion.
- The thick vertical black line is the Stoichiometric line. This is the point where combustion is perfect and no O_2 or excess air remains after combustion.

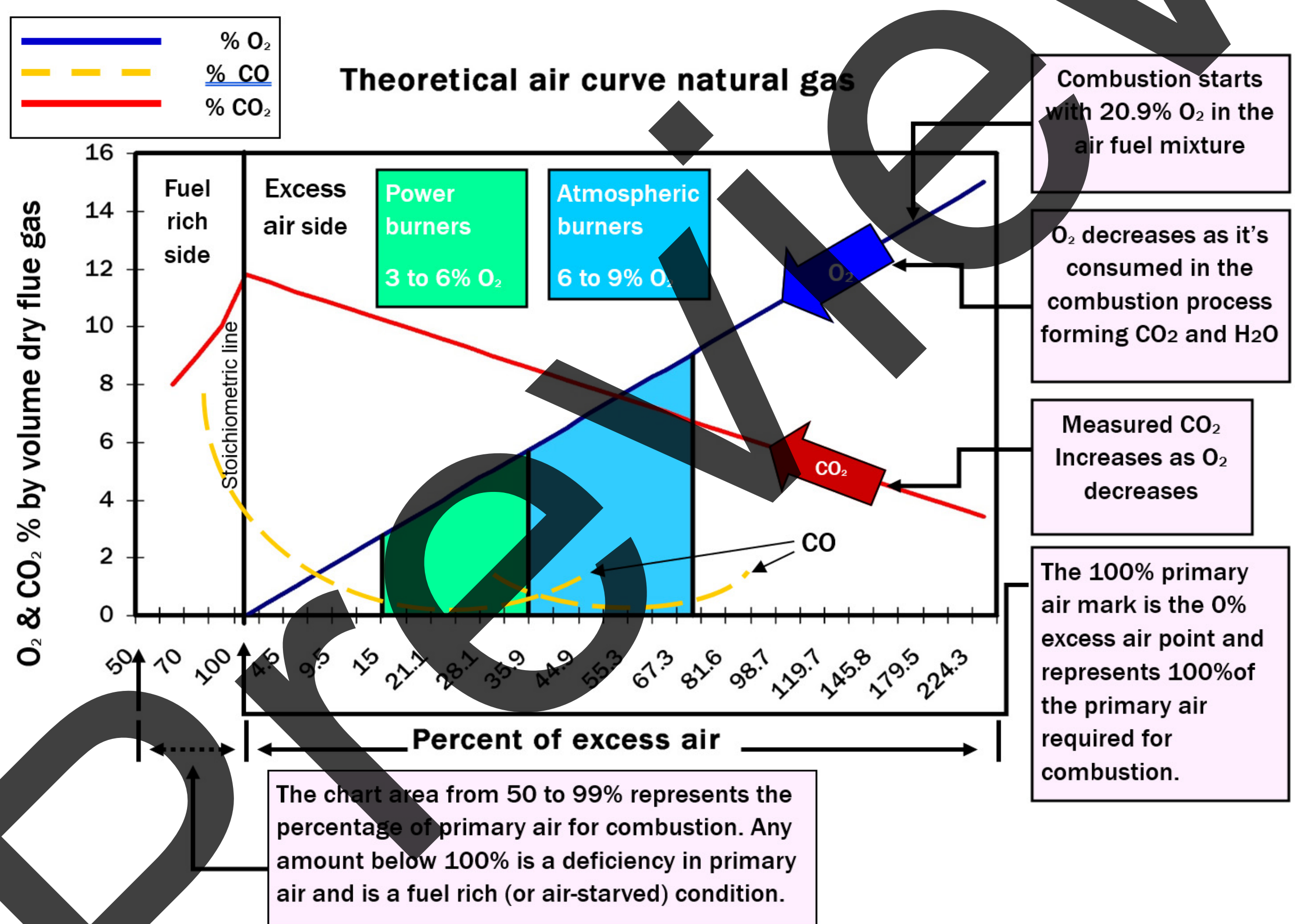


Figure 4-11: Theoretical Air Curve for plotting Natural Gas (Methane) combustion.

On the fuel rich side of the Stoichiometric line, there is too much fuel for the primary air and combustion is incomplete. Note that CO_2 is still being produced, even though there is no excess air and the CO concentration is very high. This condition can also be called air-starved.

On the excess air side of the Stoichiometric line, complete combustion is possible, provided that there is an adequate amount of primary and excess air mixing with the fuel.

Figure 4-13

Figure 4-14

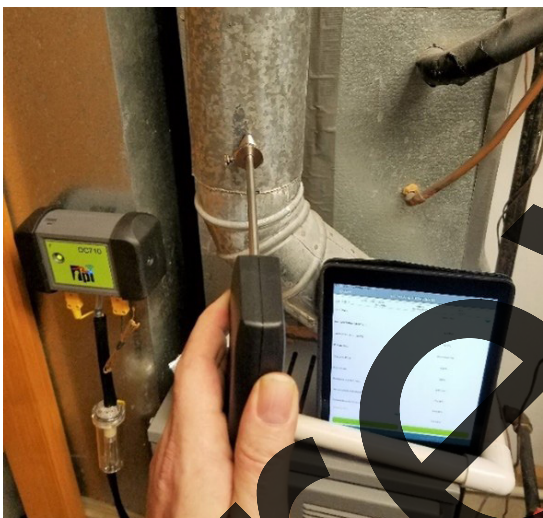


Figure 4-15

Figure 4-16

Figures 4-13 - 4-16: *Shown here are proper probe place of different combustion analyzers as well as proper sealing of the flue pipe after testing is performed.*

Evaluating the Combustion Test Results

Combustion testing is very important. Knowing how to interpret the results, and how to correct problems with the combustion process are key to completing the process of ensuring effective and efficient combustion.

Flue gases of incomplete combustion may contain hydrocarbons, CO_2, CO, N_2, H_2O and O_2. Hydrocarbons in the flue gases are often referred to as volatile organic compounds (VOCs).

Combustion Analysis Example #1

Use the information below to complete the answers to the following questions.

1. From the following stack analysis report, determine the operational status of the appliance being tested.
2. Use the theoretical air curve (OXYGEN Reference Chart) to determine if the appliance is operating within design parameters.
3. What is the problem with this appliance if any?

Stack Analysis	
Stack Temperature	425°F
Ambient Temperature	65°F
Net Stack Temperature	360°F
Oxygen	7.5%
Carbon Dioxide	7.6%
Carbon Monoxide	0 PPM
Carbon Monoxide Air Free	0 PPM
Excess Air	50%
Efficiency	81.5%
Draft	-0.02 IN WC
Fuel Pressure	3.5" WC
Temperature Rise	70°F
External Static Pressure	0.5" WC

Stack temperature & Oxygen indicators of HIGH or LOW gas pressure

CO Air Free an indicator of the completeness of combustion

Draft an indicator of air adjustment

Fuel pressure a measure of fuel input

Temperature rise or Delta T an indication of heat transfer or lack of

External Static pressure a measure of air flow when combined with manufacturers data

When the oxygen reading is plotted on the oxygen reference chart, it is easy to see when the unit is operating within the design parameters. The oxygen reading should be between six and nine percent with minimal CO production. When the oxygen reading is low and the CO reading is high, it can indicate a lack of air for combustion.

When the oxygen reading is high and CO reading is high, it can indicate too much air for combustion and possibly a high stack draft. (It is necessary to test and measure all the parameters in order to accurately diagnose any problems.) High oxygen can also indicate low gas pressure or low Btu value of the fuel.

Answers:

1. Operational Status:

Safe / Efficient Hazard / Inefficient

2. Design Parameter

Within Design Outside Design

3. What is the problem or problems?

The combustion of the appliance being tested is within the manufacturers specifications and design parameters. There is no problem with this appliance.

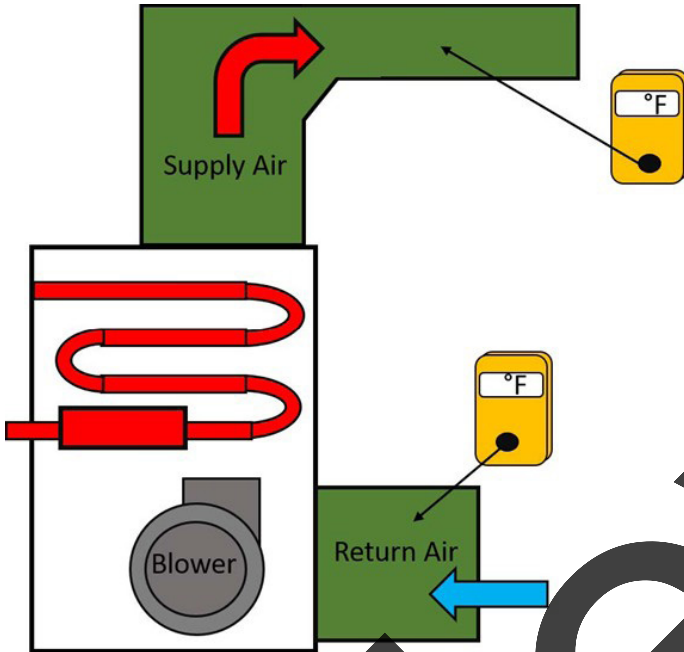


Figure 4-23: *Proper thermometer placement for testing temperature rise.*

temperature recorded. The supply temperature location should be chosen carefully. The temperature probe should be inserted into the supply plenum, far enough away from the radiant heat surrounding the heat exchangers. The probe should be out of the line of sight of the exchangers. Subtract the two temperatures to calculate the rise and compare it to the manufacturer's listed rise.

Evaluating Test Results

If the temperature rise through the furnace is too high, it can overheat. This can stress the metal of the heat exchangers and cause premature failure. In high-efficiency furnaces, the secondary exchangers are susceptible to failure due to high temperatures. Furnace efficiency is reduced as more heat is lost through the flue. If the temperature rise is too low, excessive cooling of the flue gases can occur causing condensation. This can affect venting, as the cooler flue gases lose some of their upward momentum resulting in the return of flue gas back into the space being heated. Low temperature rise also results in efficiency loss as the furnace will run longer to heat the space. Longer run times result in lower efficiencies, and possible premature failure of electrical components.

A major factor that can affect temperature rise is airflow. Furnaces are designed to have a specific airflow to ensure maximum heat transfer and proper venting. Variations in airflow can be caused by: improper duct design, clogged/ dirty filters or coils, dirty blower wheel, or improper blower speed. Too much airflow can cause a low temperature rise, and not enough airflow can cause a high temperature rise. Gas pressure can also affect temperature rise. High gas pressure can cause higher temperatures, and low gas pressure can cause lower temperatures. A technician should refer to the manufacturer's literature when adjusting gas pressure.

Calculating Airflow of a Gas Furnace

After a furnace installation is completed, the system should be tested to ensure that it will operate as designed. The manifold gas pressure should be checked and set to the manufacturer's recommendation, typically 3.5 inches WC for natural gas. A temperature rise test should be performed once the gas pressure is set. Refer to "Temperature Rise Testing" for information on performing a temperature rise test. If the temperature rise does not match the rise listed on the unit data plate, an airflow adjustment may be necessary.

Name: ______________________________ Date: ______________

Worksheet/Lab Project: Worksheet 3: Combustion Calculations.

Required Tools/Equipment: Pencil/Pen and calculator.

Required Resources: System Performance Textbook, Combustion Section.

Procedure: Calculate the correct answer for each question.

1. Calculate the CFM for the following field collected appliance data.
   - Btu Input 75,000
   - Combustion Efficiency 80%
   - Supply air temperature 145°F
   - Return air temperature 80°F

   ANSWER ________________

2. Calculate the CFM for the following field collected appliance data.
   - Btu Input 50,000
   - Combustion Efficiency 94%
   - Supply air temperature 138°F
   - Return air temperature 70°F

   ANSWER ________________

3. Calculate the CFM for the following field collected appliance data.
   - Btu Input 120,000
   - Combustion Efficiency 92%
   - Supply air temperature 140°F
   - Return air temperature 80°F

   ANSWER ________________

4. Calculate the Btu input from the following field collected appliance data.
   - Measured CFM 1500
   - Combustion Efficiency 94%
   - Supply air temperature 140°F
   - Return air temperature 80°F

   ANSWER ________________

5. Calculate the Btu input from the following field collected appliance data.
   - Measured CFM 1200
   - Combustion Efficiency 90%
   - Supply air temperature 150°F
   - Return air temperature 80°F

   ANSWER ________________

6. Calculate the Btu input from the following field collected appliance data.
   - Measured CFM 900
   - Combustion Efficiency 90%
   - Supply air temperature 130°F
   - Return air temperature 70°F

   ANSWER ________________

SECOND EDITION

SYSTEM PERFORMANCE

MAXIMIZING ENERGY EFFICIENCY IN HEATING AND COOLING

In a time where sustainability and energy efficiency are at the forefront of the everchanging HVACR industry, field service technicians and professionals, more than ever, have the ability to make a significant difference in how the equipment we install, service and maintain affects our energy consumption and the overall health of our planet.

Heating, ventilation, air conditioning, and refrigeration systems account for **40–60% of the total energy consumed in U.S. homes and buildings.** And, while efficiency ratings such as **SEER2, EER2, COP, HSPF2, and AFUE** have been developed to provide minimum standards for efficiency and to guide consumers to more efficient products, these ratings alone do not guarantee superior, or even acceptable, system performance. **Even the most advanced technologies cannot overcome the negative effects of improper system installation or neglected maintenance protocols.** A system that is improperly charged or is operating with reduced airflow will never be able to deliver its intended capacity or its advertised efficiency. It is the technician who is responsible for ensuring that the manufacturer's intent and the system's real-world performance are in close alignment with each other.

This ***System Performance training and certification series*** was developed with one goal in mind; to aid technicians in enhancing their understanding of the many industry-accepted and embraced techniques and procedures used to both verify and optimize performance of HVAC systems. In this series, specific emphasis is placed on:

- Airflow testing and verification
- Proper refrigerant charging and capacity testing
- Psychrometrics fundamentals
- Combustion efficiency

To deliver comfort and system efficiency in a safe, professional, and efficient manner, technicians must understand how heat transfer, refrigerant behavior, and the properties of air interact with each other within the system. Mastering these fundamentals allows technicians to not only keep systems running, but also ensure that the equipment is performing in the most effective and efficient manner.

AIRFLOW > CRITICAL CHARGE > PSYCHROMETRICS > COMBUSTION

esco institute

HVAC Excellence

ISBN: 978-1-930044-76-0

6 51881 10103 6