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Air-conditioning
Applications Guide
A Measurements Reference for the Advanced Technician

Part no. 400554 0523

i. Preface

This book was written as a general guide. The author and publisher have neither liability not 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 the loss of rights, material, or personal injury, or alleged to be caused directly or indirectly by the information contained in this publication.

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WARNING

Information contained is only for use by formally trained competent technicians practicing within the HVAC/R community. The manufacturers' installation, operation, and service information should always be consulted, and should be considered the first and best reference for installing, commissioning and servicing equipment. The author and publisher assume no liability for typographical errors or omissions of information in this guide.

CAUTION

EPA-Approved Section 608 certification is legally required to service building air conditioning and refrigeration systems containing CFC and HCFC (Class 1 and 2 refrigerants) . This includes the connection of analog refrigerant pressure gauges or digital refrigeration system analyzers to any stationery AC or refrigeration system/appliance.

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1 Introduction

This applications guide is intended to supplement and enhance the knowledge of a trained and qualified HVAC service technician. It is not intended as a substitute for formal technical training by authorized training organization or the manufacturers installation, operation and/or service instructions.

This technical application manual is devoted to advanced air conditioning topics, refrigeration/air conditioning application and system trend evaluation. Examples come from real refrigeration/air conditioning systems data logged in the field or lab and provide you with explanations of the trends you will soon see on your own. You will also be provided with a repeatable method of field verification of system operation using the Testo 523/556/560 along with a few other air measuring instruments.

At Testo it is our belief that a trained user makes a better customer and a trained employee is more confident and valuable to the employer. We look forward to your comments and suggestions to improving this guide. While a substantial effort has been made to include all practical uses for the refrigeration system analyzer, we look forward to your input on additional applications as they are discovered or requested.

Please forward your comments and suggestions to:

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Using this Manual

- ***Notes*** : are suggestions and insights to more effective work
- ***Cautions*** : are information that may effect testing accuracy, consistency, or might lead to equipment or product damage
- ***Warnings*** : are information relating to potential physical harm

About Testo Refrigeration System Analyzers (RSA)

It has been four years since the US introduction of the first generation of Testo refrigeration products. Our new generation of the Testo line of refrigeration system analyzers (RSA's) will continue to change the way the HVAC/R world troubleshoots, commissions and services AC & refrigeration systems. Although the first generation of refrigerant products was highly successful, Testo has listened to our customers' desires to develop a product line with the diversity to meet your most demanding applications. Testo has completely retooled and reworked the refrigeration product design from the hook, which is now a quick locking carbineer, to a backlit sight glass that aids in refrigerant recovery allowing the technician to see when the last drops of liquid refrigerant are removed. Larger valve handles that can be recessed or extended make it easier for large or small hands to operate the gauge porting, and valves that can be field serviced or replaced without the need for special tools. Leading the refrigeration industry in innovative technology, Testo will again surpass your expectations in digital refrigeration technology. The next generation has incorporated a long list of new features that will increase measurement accuracy, reduce equipment-servicing time, and provide a means of tamperproof field verification, while streamlining field operations. Added this year in all instruments is the ability to print the measurement results on site via wireless printer, high stability ceramic relative pressure transducers, a large backlit display, and intuitive user operation. Three and four valve designs are available with a 3/8- evacuation port on four valve manifolds. High durability valve handles with Teflon seats, a backlit sight glass, and display, hose holder with integrated LCD protection, and in 556/560 models wireless temperature sensors and data logging. Incorporated into the 560 is also a vacuum sensor that reads in microns, "hg, or Pascal's of pressure. With its data storage capabilities (556/560), USB output, real-time graphic capabilities in the online mode, joined with the superior accuracy, no other product made can compete at any level.

After several years of rigorous testing in the lab and the field, the digital manifold has been proven to deliver laboratory accuracy results in demanding field service. The multi-functionality, reliability, repeatability, and unique features set the Testo products apart from the competition.

Technicians will appreciate the ease of use, the wide range of applications, including the ability to upgrade to new refrigerants along with the wireless printing capabilities on all instruments from the Testo 523 to the Testo 556/560. Small features like an integrated protective boot and lighter yet more robust design has not been overlooked on all models. Future accessories for the 556/560 models including a wide variety of temperature probes, digital scale, amp clamp, and oil pressure transducer allow for quick verification of proper operation and field documentation or real-time monitoring and troubleshooting. Pressure-temperatures chart are a thing of the past, and commissioning equipment to anything *less* than the manufacturer's standard will become uncommon for all Testo users. Technicians can get more done with higher accuracy and quicker results than ever possible. Field documentation can be done with little effort, providing any interested party with the information needed to evaluate system operation in the field or the office.

Testo has taken a quantum leap forward in AC/R measurements allowing anyone from the lab technician to the service technician to deliver consistently accurate results to owners, manufacturers and end users of air conditioning and refrigeration equipment

The Testo 523/556/560 digital refrigeration/air conditioning system analyzers are a multipurpose tool designed for every day use replacing a gauge manifold, superheat or subcooling thermometers, Pressure-Temperature charts, etc.. with a rugged hand held versatile tool.

Pressure Sensors

Unlike traditional mechanical gauge sets, the Testo 523/556/560 has dual ceramic pressure transducers or pressure-measuring sensors; an advantageously used pressure measurement technology. Ceramic pressure-measuring cells have a measuring accuracy and repeatability that is stable over a very long time; therefore frequent calibration is not needed. The high and low side sensors are selected for an operating range that will provide the highest accuracy for their desired measuring range, allowing accurate pressure measurement over the full range on either side. (.5%fs) The different range of pressure transducers for the high and low sides respectively are calibrated in regards to their zero points, coefficient of thermal expansion, and sensitivity so they can be used in wide ranges of temperatures as extra-high precision pressure transducers. Ceramic pressure transducers are designed so the pressure sensitive part is exposed directly to the measured media. Thanks to excellent chemical resistance, ceramic pressure transducers do not require additional protection from oils, refrigerants, or acids and additionally will withstand the shocks from normal to rough handling without ever affecting the sensor calibration. While traditional gauges require frequent trips to a calibration house to assure their accuracy (often a procedure never performed), the calibration of the pressure transducers in the 523/556/560 is only recommended annually.

The ceramic pressure transducers or sensors can be field nulled, (often referred to as zeroing) and as good practice should be whenever refrigerant pressure is removed from the sensors, or when the hoses are purged to change refrigerant types.

A null value is different than having a value of 0, since 0 is an actual value. When a variable has no value, it considered being null. Because all standard pressure gauges are calibrated for sea level, (0 psig) if the sensor was zeroed rather than nulled, the current atmospheric conditions would not be considered. If the gauges were brought back to 0 psig outside of sea level, (a procedure often performed with mechanical gauges and some electronic) the accuracy of the gauge would be affected by the current elevation with respect to sea level. Because Testo uses a nulling procedure rather than zeroing, the instrument the sensor can be brought back into calibration in relation to the current atmospheric conditions or ambient pressure, which thus serves as a reference pressure. Quite simply, when there is no refrigerant pressure on the sensor, the reference pressure and the sensed pressure are the same. Nulling the RSA sensor brings it back to a perfect zero psig regardless of the atmospheric conditions provided the pressure is removed from the sensors.

Superheat and Subcooling Measurement

Thirty on board temperature pressure charts provide unparalleled detail and accuracy of refrigerant saturation temperatures, superheat and subcooling. Unlike traditional paper charts no interpolation of the temperature-pressure relationship is required. It is now possible to measure and set superheat and subcooling with laboratory accuracy in the field as the Testo 523/556/560 reads pressures and temperatures to the tenth of a psi and tenth of a degree and automatically calculates real-time superheat and subcooling values. Temperature measurement is just as critical as temperature when commissioning and servicing equipment.

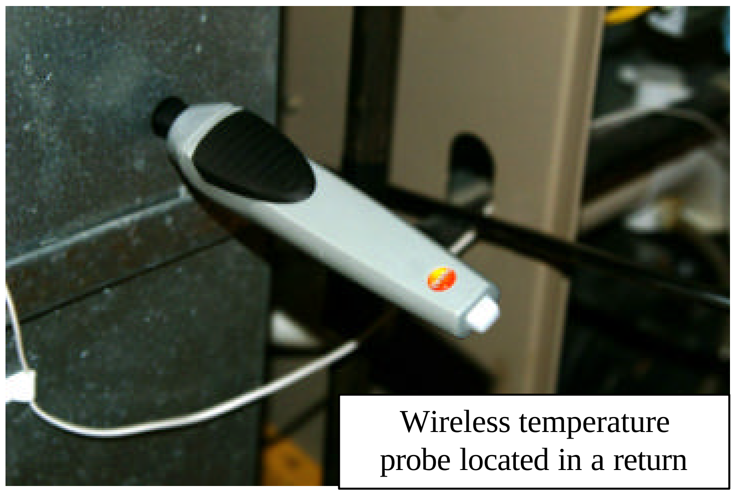
Temperature

The platinum based (platinum film on a ceramic substrate) 4-wire construction, of the spring loaded temperature sensor (Pt-100) has a very low mass (yielding a fast response) and is not affected by stray voltages that may be present on the refrigeration equipment. Unlike traditional K-type thermocouples, the sensor is electrically isolated from the RSA. Isolating the temperature sensor electrically form the system eliminates the possibility of incorrect temperature measurement resulting from stray electrical currents or ghost voltages often present on improperly grounded refrigeration and air conditioning systems. Because the resistance of a Pt100 sensor bears an absolute relationship to temperature (unlike a thermocouple whose output depends on the difference between the hot junction and cold junction) no special compensating circuit needs to be provided in the electronics. In short, the Pt100 has a wide operating range, excellent accuracy, good linearity, excellent physical strength, long-term stability, and is the preferred sensor for all industrial processes where accuracy and repeatability are required. Additionally, Pt100 probes may be replaced without recalibration of the RSA instruments. Sensors are available in lengths up to 40 feet. The Velcro-elastic strap provides insulation from ambient air along with positive contact to the refrigeration line from ¼" to 3" in diameter. Air and immersion probes are available to further enhance your testing applications.

Time

Additionally incorporated into the system analyzer is a new dimension; time. The entire new generation of RSA products incorporates a real time clock that permits accurate documentation of the time and date readings were recorded via the wireless printer or data logging. Testo was first-to-market with a complete line of refrigeration system analyzers that incorporate data logging, and now the first to bring wireless printing to the complete line. Owners of Testo combustion or other test equipment that already use a wireless printer will benefit from cost savings, as the printer is universal to all Testo products. Data logging (556/560) allows the service technician and or system analyst to evaluate system performance over a period of time from a snapshot to days with easy to use software, A printout of the final operating parameters on all RSA products allows for field documentation of operating at system startup or pre and post operation.

Wireless Capability



Wireless temperature probe located in a return

The Testo 556/560 are both upgradeable to wireless temperature capability. Wireless technology will enable temperature measurement form remote locations for calculation of evaporator superheat at an outdoor condenser, monitoring of return and supply air temperatures for outside, or a remote outdoor air temperature. The wireless probes and the built in temperature probes can be assigned as needed for a number of field applications.

Data Management

Wireless printing is standard in all models of the new generation of refrigeration analyzers. All measured and calculated parameters can quickly be field documented without error in seconds. Pre and post measurements allow for documentation of "as found" and "final" performance. System commissioning on new startups or major component repairs like compressor replacement are easily documented for the office and the customer.

The most significant advantages of data

management and analysis are apparent when data from a Testo 556/560 is read, analyzed and managed in the Testo PC Software. It is now possible for the technician designer, engineer, service manager, or a lead technician to spot trends, benchmark systems, verify proper/design operation, provide real-time system operation to a manufacturer or other interested party in an *tamperproof data format* that can be graphed to provide a "digital window" into the refrigeration/air conditioning system. In the online mode, system high and low side pressures, saturation pressures, measured temperatures, along with superheat and subcooling can be viewed on an auto-scaling graph real time graphing format. All measurements or each individual measurement can be viewed at once. System hunting, erratic operation, or other trends can be quickly spotted and documented using the optional software.

Testo has not overlooked small, but important details that make the products well suited for field use. Owners of Testo products have come to expect a rugged field service product with such features as water and acid resistance construction, a backlit displays and sight glass, user selectable units, and a battery life indicator to provide flexibility and reliability in their work.

3 Why test?

Making and interpreting measurements is a crucial part of any job involving service, installation, design verification, engineering, or factory support of HVAC/R equipment. When it comes to verifying proper operation of the installed equipment it is critical that measurements made in the field are just as accurate as those made the laboratory. At Testo we believe that we all have an obligation to assure that the equipment is operating at peak performance levels for the benefit of consumers and end users of HVAC/R equipment, equipment manufacturers, utilities, the nation's energy future and the environment.

Today, most AC & refrigeration equipment is still being serviced and adjusted with traditional mechanical manometers and manifold gauge sets using limited resolution temperature pressure charts or hard-to-read refrigerant gauge scales to determine evaporation and condensation temperatures. Measurement errors can be the result of interpolation errors, calibration errors, poor repeatability of the measurement, and most importantly not having a procedure in place to consistently repeat the measurement process. Before one can rely on these measurements, it is imperative that the same results can be obtained by anyone using similar instrumentation.

Theories vs. facts

Air conditioning is not theory; *it is a collection of scientific facts*. It combines physics, chemistry, and earth science. We are concerned with the science of HVACR. Science involves proven scientific facts that are repeatable anywhere in the world. For example, "pure" water will boil at 212° F (or 100° C) anywhere in the world at sea level. Air conditioning is a well-proven science, and nothing more than that. As with any science you must master the scientific principles, terminology, and mathematical relationships to fully understand what is happening.

Start with the basics

As you approach the task at hand, it is important to master the basics or fundamentals first. It will always come back to that. Many times a young mechanic finds the problem before a seasoned mechanic just because the young mechanic has recently mastered the basics and is looking for the simple problem that the seasoned technician has overlooked. Additionally, a seasoned technician may see the problem, remark on it then completely pass it by because they think it can't be that simple.

To be a good mechanic it is important to use your senses to troubleshoot the equipment; to look, listen, touch the lines (refrigerant lines not electrical lines!), make measurements and compare them to a known. Form a concept in your mind about what is happening, and then use the science you have learned, and the measurements you have made to either prove or disprove the concept.

If you are not sure of the science, you need to know where to find it. That is what this manual is about: scientific facts. This manual will put into laymen's terms what you need to know to be successful in the air conditioning business. There are many texts that are of high quality dealing with this subject matter, but none that consolidate the information into what the technician really needs to know, painting the big picture about how all of these systems work together.

4 Measurement Technology: Why go digital?

Many service technicians are reluctant to use digital instruments; there is a certain comfort in using what we are used to. The truth is digital instruments are faster, more accurate, more reliable, and have a higher repeatability than most analog tools. Digital instruments stay in calibration, allow trending, allow more complex functions and save time. Digital instruments allow data to be recorded and reported with out human error, and provide reliable and accurate results for you and your customers. Data can be recorded much faster than any technician could ever do the calculations and data can also be recorded whether or not the technician is there to see it. In most cases, the data is an un-editable record, so what you see was what was measured at the jobsite. System trends and symptoms can be recorded with the function of time allowing the user to track cycles, and determine if other systems like automation or shift changes are the cause of the problem. Permanent records allow the user to track system changes and determine if the system is operating within the design parameters or if changes have taken place.

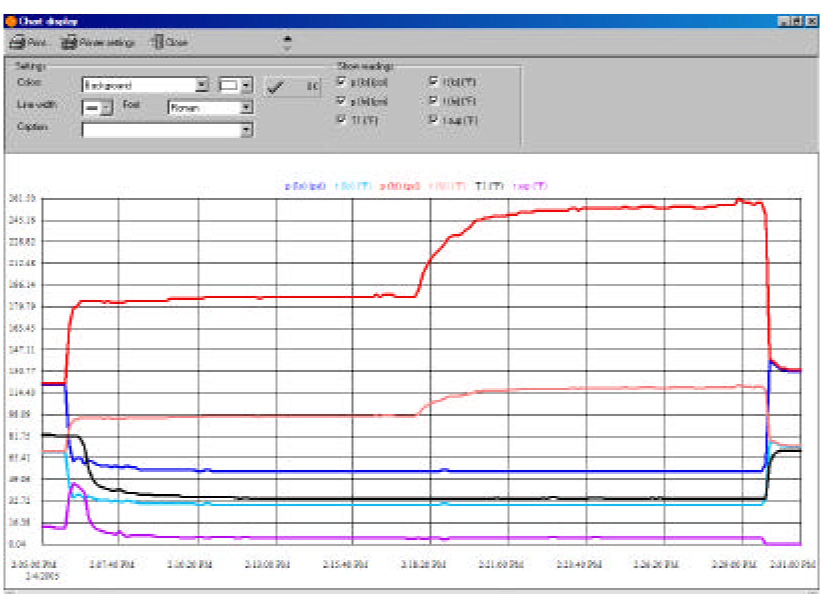
YOU CAN TRUST YOUR DIGITAL TOOLS!!

Using the Testo 523/556/560 refrigeration analyzer is no different than using a conventional manifold gauge set, yet the system operation information available to the user is far superior. The high and low side connections are attached to their respective sides, and the readout of the refrigerant pressures and saturation temperatures are displayed. The analyzer reads pressure and temperature only, so it is important that the refrigerant is known before verifying the saturation temperature as the 523/556/560 calculates the refrigeration saturation temperature. The refrigerant selection can be changed any time during the analyzer use. A temperature sensor (attached to the temperature probe/data cable port) will allow the 523/556/560 to calculate refrigerant superheat or subcooling and/or measure line, fluid or air temperature with an auxiliary probe attached.

The Testo 523/556/560 is a laboratory-accurate instrument designed for use in the field by all refrigeration and air conditioning service technicians. The 523/556/560 is designed to replace your existing manifold set, and should be the first tool of choice when working on refrigeration systems as additional information on system operation, and an operational performance curve can be obtained when desired.

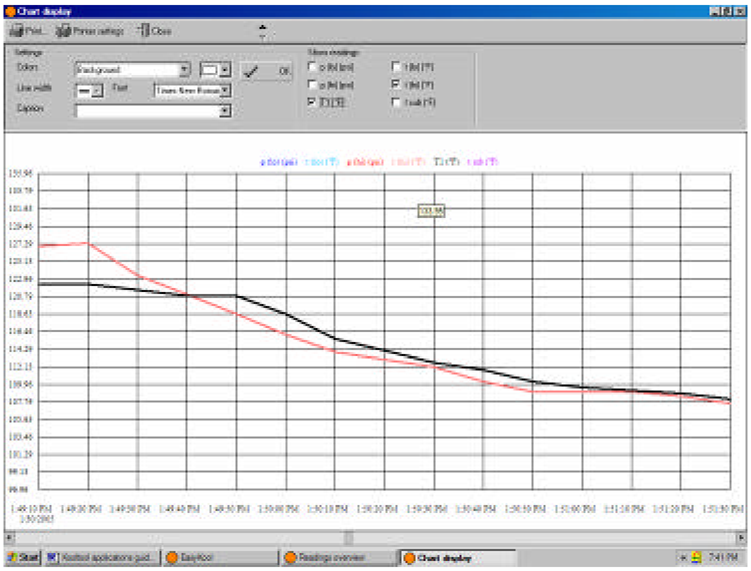
Going digital may feel awkward at first. From experience you know approximately where your gauge pressures should be. Sometimes, unless the pressures are outside of the normal operating range, you may not even pay attention to the actual system pressures. A large part of the problem is that analog gauges are interpreted by the user. They are only an indicator of the approximate pressure. If 10 users were to attach their gauges to an operating refrigeration system, even if all were calibrated, there would be a range of pressures and saturation temperatures interpreted by the users. (We know, we have tried this!) Digital leaves no room for interpretation; it is what it is. With digital, you will find yourself setting up the equipment exactly to the manufacturer's specifications because you can. If the manufacturer calls for 8° of subcooling, you can charge the system to exactly 8°. There is no learning curve beyond learning to navigate the menus of the analyzer.

When using the software it is important to not let the amount of information obtained by the system analyzer overwhelm you. The Testo 523/556/560 can measure and store over 1000 snapshots of the system operation including the high and low side pressures, corresponding saturation temperatures, actual measured temperatures, and the calculated superheat or subcooling at any given instant during system operation. All of the information can be displayed graphically on one page in the EasyKool PC software. This allows the user to see the big picture, and notice things like TEV hunting, pressures rising or falling, cycling, and see when the system has reached steady state operating efficiency.



The TXV equipped system curve shown on the left displays the symptoms that were later tracked to a failing capacitor.

All or part of the information can be displayed at once making it easy for the service technician, installer or lab technician to view the suspected problem in greater detail than ever before. Using the refrigeration system analyzer will forever change to way you troubleshoot refrigeration/air-conditioning problems, as you will have a "digital window" into the refrigeration system.



Left, information extracted from a system operation curve showing a system temporarily loosing control of its subcooling due to condenser fan cycling.

Doing it right, digitally

Technicians are constantly making measurements. What do we do with them? Making measurements without knowledge of how to use them is a more dangerous than not making them at all. If we don't know what they should be, why even make measurements? Imagine if your doctor took your temperature but had no idea that it was supposed to be 98.6°?

Day after day technicians are leaving a legal document (a work order) with a customer that contains information that the technician may or may not understand. It is serious business to write things like verified correct airflow, checked charge, verified temperature drop across coil. How many times have you seen the problem right on the equipment check sheet? The measurements were made but the technician had no idea that there was a problem. Realize that when you say operation is "OK", it better be "OK", or your company's reputation is on the line. It happens more often than you might think. It may only be a matter of time before it comes back to bite you.

Often we work in ranges, "the temperatures should fall within a XXX to YYY", or "the superheat should be ***about XXX"***, "there is approximately YYY CFM", etc. Part of the reason is that the <u>*typical instrumentation we are using is **about** accurate*</u>. We guess that the air conditioning system or furnace is working as it was designed since there is cool air or heat coming from the registers. These are not the actions of a professional. Air conditioning and heating is an exacting science that deserves exact tools and instrumentation. We are not saying the instrumentation you are using is of no value at all, but sometimes the instrumentation we are using has so much internal error or error inherent with the measurement procedure that it is really of little to no value.

Try this: At your next service meeting have all your techs bring in their manometers, thermometers and sling psychrometers or digital hygrometers. Hopefully, they all have these necessary tools to do the job! Have your techs each make readings of CFM, temperature drops and rise, return air wet bulb and dry bulb on an operating test system. Measure the suction and discharge pressures and calculate superheat and subcooling. Have them write down the information as you go. If their results are not the same, how would they ever consistently set up equipment in the field? This might be the most valuable thing your company can do on a quarterly basis. Use simple math to calculate the percentage of error. Check your techs' instruments; it's your reputation on the line. Professional technicians make measurements for a living. Making an investment in digital instrumentation will reap benefits for your company for years to come. If you don't want to make a big jump, at least make a small investment in the technology and see how it works for you. Try it; those that have will never go back.

Regarding measurement procedure and calibration standards can you describe a way to accurately measure airflow across a coil? How about multiple ways? Do you know how and why to charge by subcooling and superheat? Can you verify the real-time superheat or subcooling? Do you have a repeatable procedure in place to set up equipment to the same standard consistently every time? Do you trust your test instruments? If so what standard do you use to verify their accuracy? Can you verify the equipment you work on is working to its designed capacity? How do you know the equipment is operating as designed? Proper use of digital instruments and a prescribed testing procedure can help you answer these questions. Do not rely on just any instruments, but instruments calibrated with standards traceable to the National Institute of Standards and Technology (NIST). If you are not using instruments that meet these standards how do you know they are accurate?

Digital refrigeration technology is allowing us to do what we have not been able to do before, or allowing us to do it in a time frame that has not been possible. Digital instrumentation is bridging the gap between the laboratory and the field allowing technicians to set up equipment to a higher standard than ever before possible. With quality instrumentation your techs can significantly reduce the error in measurement, reducing callbacks increasing customer satisfaction and taking your company to a new level of professionalism. With digital you can spend you time *using* measurements instead of *making and remaking* them. The procedures are always easier, and with high quality instrumentation, accuracy can be guaranteed.

How many times have you spent your time babysitting a refrigeration system waiting for the problem to happen again? Then when it does you still see the symptoms but not the cause. You make a repair or an adjustment and wait all over again. Wouldn't it be simpler to data log the problem while you are working on the next unit?

Quality digital instrumentation can answer all of these problems and questions allowing the technician to work smarter and not harder. It is now possible to be as accurate in the field with measurements as they are in the laboratory. Technicians can have confidence in their tools. Their tools can make them more productive making your company more profitable and professional.

5 AC/R Process Basics

Only two things can be adjusted in nearly all residential air conditioning systems: charge and evaporator airflow. Think about it: you cannot adjust the voltage, amperage, condenser fan speed, temperature drop or temperature rise across the coils, all of these things are a function of charge and airflow. There is nothing else that requires anything more than inspection on a residential air conditioner. Other factors that can affect operation of an air conditioner might include things like improper line sizing, air bypassing the evaporator, incorrect wire sizes, or a loose expansion valve bulb, however, for the remainder of the discussion we will assume a proper installation was done.

When new equipment is installed a technician should go through a pre-start checklist. While conducting an inspection, a pre and post performance measurement should be made. Technicians should verify wire sizes are correct, the proper fuses have been installed, the lines are the correct size, equipment placement is proper, and a proper evacuation has been preformed. The installation directions should be checked to verify the installation was made according to the manufacturer's instructions.

Before any air conditioner can be properly charged, the airflow must be properly set. This means airflow across the evaporator must be set to the manufacturers specifications. (Usually 400 CFM/Ton for A/C, and 450/Ton for heat pumps) Airflow should always be set prior to system start-up. A good time to set the airflow is usually while the system is being evacuated. *Airflow cannot and must not be set by measuring the temperature drop across the evaporator coil.* It must be set utilizing a method that measures the actual CFM (Cubic Feet per Minute of air) flowing across the coil.

Using a capture hood and setting the airflow to meet register requirements will not do the job. The capture method does not verify airflow across the coil. It does not take into account leakage that is present in all duct systems. In order to verify proper **total system** operation, the airflow at the coil and the registers must be verified. If the registers do not have the required airflow as measured with the capture hood after airflow is set across the coil and the system is balanced, the duct system must be evaluated and/or be properly sealed.

The most accurate way to verify airflow across an evaporator coil is using a mini vane anemometer. The mini vane does not require corrections for air density (corrections for pressure or temperature or humidity), and CFM can be directly calculated in duct dimensions are input into the measurement device. If other methods are utilized, care must be taken to assure that air is not leaking in or out ahead of the point the measurements are being taken. It is imperative the airflow across the coil is correct. If the airflow is too high or too low it will adversely affect the system operation. If information on pressure drop verses CFM is not available, use an alternate method.

After airflow has been set, the system refrigerant charge must be verified. A standard condenser comes with enough refrigerant to operate with a 25' refrigerant line set and a matched evaporator coil. If the installation requires anything different, the charge will have to be adjusted. Follow the manufacturer's prescribed charging procedure.

In order to properly charge refrigeration system the type of metering device must be verified, and accurate entering wet bulb and dry bulb temperatures must be made along with the air temperature entering the condenser. Different types of metering devices require different measurements to be made. Some manufacturers have special charging requirements that should be followed. If none are available a charging calculator should be used. There are many different types available from different manufacturers. A close examination will reveal that they are all almost identical. In general; physics is physics and technicians will find that almost all air conditioning systems operate with similar characteristics. The laws that govern science do not change. Temperature transfer is a function of time, temperature difference and turbulence. Since the time and turbulence are a factor of the airflow set at a nominal 400 CFM/Ton (450 CFM/Ton) for heat pumps, the operating characteristics will be almost identical across the board.

Trane and Carrier Charging Calculators

A common problem among service technicians is charging refrigeration equipment during low ambient conditions. With a digital AC/ Refrigeration Analyzer like the Testo 523 or 560, and an accurate wet bulb thermometer/hygrometer like the Testo 605-H2 (or 625) and a charging calculator it is possible (and easy) to accurately charge air-conditioning systems at ambient temperatures as low as 55° outdoor air, with indoor wet bulb temperatures as low as 50°.

CAUTION

Below 70° dry bulb indoor air temperature, the wet bulb temperature must be used.

With low indoor ambient temperatures, wet bulb temperature is required because wet bulb takes into account the total heat in the air. There must be enough heat (latent and sensible) in the air to evaporate the refrigerant in the evaporator coil at a rate equal to the rate it is being fed into the evaporator coil or the evaporator will become flooded (overfilled with liquid refrigerant). It is imperative that capillary tube systems are properly charged. A few ounces of refrigerant can drastically affect the operational characteristics of an evaporator using a capillary cap tube or other fixed type metering device. In order to understand system charging, a few things must be known, starting with the basics as detailed in the following sections.

6 Understanding airflow and how to measure it

CAUTION
If the airflow is not set correctly, the system cannot operate as designed!

Airflow is one of the most overlooked yet the most important parts of verifying proper operation of air conditioning systems. Low airflow can cause symptoms like evaporator freezing, low system capacity, poor distribution and high-energy consumption. High airflow can cause symptoms of poor humidity removal, higher energy costs, noise, drafts and water/equipment damage due to water droplets blowing from the evaporator coil from excessive air velocity. Air conditioners are designed for a nominal 400 CFM (450 for heat pumps) of airflow per ton.

To operate with the designed capacity the airflow has to be set to the manufacturer's design criteria at the evaporator coil. Temperature drop across a coil will vary with the latent load (humidity) the more humidity, the more cooling energy goes to converting water vapor to water. The temperature drop across the evaporator can easily be between 16° to 24° F. Therefore it is imperative to set the airflow to the proper range and not to rely on the temperature drop across the coil to verify system performance. It is important to understand that the conditions of the air entering the coil will not normally affect the designed temperature difference of the coil. It will however affect the temperature of the air leaving the coil.

As the humidity of the air entering the coil goes up, the temperature drop across the coil decreases. If the system uses a fixed- type metering device, the evaporator superheat will increase proportionally with an increase in humidity. System utilizing a thermal expansion valve (TXV) under conditions of extremely excessive heat and humidity (high load) can see an increase in suction pressure and temperature raising the temperature of the evaporator above the design temperature difference of the coil in attempt to maintain designed superheat to control the load. While this is not common with air type evaporators it can and it does happen. Under these conditions the equipment would be considered to be operating far outside of its design conditions.

CAUTION
Temperature drop across an air conditioner evaporator coil cannot be used to set the airflow.

The most common and easiest way to verify and set airflow is to use one of the following methods:

1) Rotating Vane Anemometer
2) Pressure drop across the dry evaporator coil
3) Total external static pressure method
4) Pitot tube and digital manometer
5) Velocity Stick (Hot Wire Anemometer)
6) The temperature rise method (Sensible heat formula)
7) RPM and manufacturers fan curve (Belt or VF Drive)

The airflow must first be set according to the equipment design not to the air delivered at the registers. While the design of the duct system is imperative for proper air distribution to the conditioned space, air measurements are only to be measured at the appliance for the equipment commissioning procedure. Due to leakage inherent with all ducting systems, airflow cannot be measured at the registers to verify correct airflow across an evaporator coil or heat exchanger. The problem is not with the operation of the equipment if the system will not heat or cool the home after the airflow is properly set at the appliance and the equipment operation is verified to be correct. The ducting system should then be evaluated for excessive leakage, proper sizing and proper design. A review of the heat load calculation may be required to verify the equipment selection was correct if the system still will not perform properly.

CAUTION

Do not adjust the airflow to change system-operating characteristics like air noise or low register airflow or decreased capacity and or system damage could result.

Although 400 CFM/ton goes across the evaporator coil, only about 350 CFM /ton is delivered out of the registers. Approximately 50 CFM per ton is lost due to leakage from poorly sealed duct systems.

When making any air flow/quantity measurements for cooling or heating all dampers must be in their normal operating position, all equipment panels and doors must be in place. Many manufacturers have a removable base pan for bottom return. If a side return is used, make sure the bottom return is properly sealed, the return airdrop is securely fastened, and a proper sealant, (like Mastic®) is used to seal the connections. A digital manometer can be used to check for pressure differential between the bottom side of the base pan and the surrounding air. The fan must be operating using the speed that will be operating when the cooling is in operation. The condensing unit should not be in operation during the measurement process, as moisture that will accumulate on the evaporator coil will significantly affect the pressure differential readings. It is usually easiest to pull the service disconnect for the condensing unit, locking out the condenser. This will allow the system to operate in the cooling mode without conditioning the air during the system airside commissioning.

Rotating Vane Anemometer

For highly accurate quick measurement, the rotating vane anemometer is the best way to measure airflow. Vane anemometers have several advantages over any other method. The primary advantages are speed, accuracy, and ease of use. Vane anemometers do not require air density compensation due to air temperature, humidity, or atmospheric pressure. The mini vane allows for a full duct traverse with an automatic calculation of the CFM in the duct if the dimensions are input into the instrument before the measurement is taken. **It is imperative that the ducting attached to the appliance, and the base pan, if side returned is used, is sealed**. Air leaks up-stream of where the measurements are made will significantly alter the actual reading obtained with this method. If done carefully the measurement error will be less than 3%. Changes in yaw and pitch of the probe head in the duct as much as 10% will result less than 1% error in the measurement making the mini-vane an ideal probe for field air measurement.

Pressure drop across the dry evaporator coil

An easy way to quickly verify airflow is to measure the static pressure drop across the evaporator coil, and compare the reading to that specific evaporator coil in the manufacturer's literature. With a digital manometer, and a pressure drop vs. CFM chart, airflow can be *set close to specification* across a dry coil in a matter of minutes. The positive probe should be inserted ahead of the air entering the coil and the negative probe immediately downstream of the coil. The reading obtained will be the pressure drop in inches of water column or Pascal. **NOTE*:*** *While this measurement is accurate enough for setting up equipment, it is not accurate enough to make a field measurement of the system capacity.*

Total external static pressure method

The total external pressure method is preformed in the same manner by measuring the pressure difference across the furnace (supply to return) and using the manufacturer's chart. The CFM can also be set quickly and accurately using this method, but again, *the measurement process is not precise enough to use for verification of the system capacity.*

Pitot tube and digital manometer

If the return airdrop is tall and straight enough the airflow into the appliance can also be very accurately verified using a Pitot tube and a digital manometer. However, this method is very time consuming. By traversing the duct, (making several pressure measurements in predefined locations) and performing a couple of simple calculations to convert velocity pressure to speed in feet per minute, the air flow is determined by multiplying the average air velocity by the cross sectional area of the duct to obtain CFM. *It is imperative that the ducting attached to the appliance, and the base pan, if side returned is used, is sealed.* Air leaks up-stream of where the measurements are made will significantly alter the actual reading obtained with this method.

Velocity Stick (Hot Wire Anemometer)

A hot wire anemometer can also be used in the return air duct to verify flow. Using this method, (Pitot tube or anemometer), it is important to carefully traverse the duct in order to get accurate results. Until the development of the mini-vane anemometer, the Pitot tube and velocity stick were the most precise field measurement of airflow in a duct. Both however are sensitive to changes in air density outside of standard air conditions. If done carefully most technicians can achieve accuracy within 20 CFM per ton or 5%.

The temperature rise method (Sensible heat formula)

The temperature rise method is a last resort, and may be used for fossil fuel and electric furnaces. Because the heat content of natural gas varies from day to day and hour to hour, the temperature rise method should only be used to get the airflow close to the manufacturer's recommendation, and cannot be used for AC system capacity verification. To verify CFM in a natural gas furnace, **first** let the furnace run for ten minutes or until the stack temperature stabilizes, allowing the appliance to reach steady state efficiency. Using a combustion analyzer determine the steady state operating efficiency of the appliance and multiply it times the BTUH input to get the output BTUH of the furnace. *(Remember, if the heat is not going up the stack, it is going into the house.)* If a combustion analyzer is not available, alternatively, the manufacturer's literature could be used to determine the output BTUH's of the furnace provided the manifold pressure is correct set and the BTU content of the fuel used is consistent. (The manufacturer's tag is a good place to look for this.) *<u>Do not use</u> efficiency information from the yellow energy guide label, as this is AFUE, (Annual Fuel Utilization Efficiency) and takes into account the efficiency losses at start-up of the equipment.* **Second** measure the temperature rise across the heat exchanger. **CAUTION** It is important that your probe be out of the line of sight of the heat exchanger when making these measurements as the temperature probe can be affected by radiant heat from the heat exchanger. **CAUTION** If the furnace has a bypass humidifier, make sure the bypass is closed. Next enter your results into the sensible heat formula (shown below). This is an approximate method as the heat content of natural gas varies across the United States and even from the same meter from hour to hour, and there is additional heat added from the blower motor. Heat added by the motor can be as much as 300 watts or 1024 Btu.

NATURAL GAS/LIQUEFIED PETROLEUM (PROPANE)

CFM = (Input BTU x steady state efficiency) / (1.08 x ΔT)

ΔT is the temperature rise across the heat exchanger in degrees Fahrenheit

This will give you an approximate CFM; although it will be very close to the actual if the measurements are made accurately and the heat content of the natural gas is near 1000 btu/cf.

ELECTRIC HEAT

For an electric furnace the airflow measurement procedure is the same. Allow the appliance to operate until the temperature rise stabilizes. Measure the temperature rise again out of the line of sight of the electric heater, along with the incoming volts and current draw in amps to the electric strip heaters. Enter the information into the following formula.

$$CFM = (Volts \times Amps \times 3.41) / (1.08 \times \Delta T)$$

FUEL OIL

For fuel oil the procedure involves verifying the nozzle size and the correct fuel pressure. After the Nozzle size in GPM (gallons per minute) is known and fuel pressure set, the combustion efficiency must be measured with a stable stack temperature, and the temperature rise across the heat exchanger recorded.

$$CFM = ((Btu/gal\ oil) \times (Nozzle\ size\ GPM) \times (combustion\ efficiency)) / (1.08 \times \Delta T)$$

For fuels other than those listed above we have included a chart for your convenience. For residential applications the standard values will be all that is required as small changes in the heat quantity of fuel will have a very small impact on final calculations.

BTU Content of Other Fuels

Since the actual heat content of different types of fuels varies, the approximate average values are often used. The table below provides a list of typical heating fuels and the BTU content in the units that they are typically sold in the United States. The figures below are general references for residential heating applications only. Commercial and industrial users should obtain more precise values from their fuel vendors.

Table 1: Average BTU Content of Fuels

Fuel Type	No. of Btu/Unit
Fuel Oil (No. 2)	140,000 per gallon
Electricity	3,412 per kWh
Natural Gas	1,025 per cubic foot
Propane	91,330 per gallon 2500 per cubic foot
Wood (air dried)*	20,000,000 per cord or 8,000 per pound

Pellets (for pellet stoves; premium)	16,500,000 per ton
Kerosene	135,000 per gallon
Coal	28,000,000 per ton

From U.S. Department Energy

7 How to properly charge a system

Remember, with all residential air conditioning systems there are only two things that can be adjusted, charge and airflow. Think about it, we can't adjust the voltage, amperage, condenser fan speed, temperature drop or temperature rise across the coils, there is nothing else to do beyond mechanical inspection of a residential air conditioner. Other factors that can affect operation of an air conditioner might include things like improper line sizing, air bypassing the evaporator, incorrect wire sizes, or a loose expansion valve bulb, but for the remainder of the discussion we will assume a proper installation was done.

When new equipment is installed a technician should go through a pre-start checklist. Technicians should verify wire sizes are correct, the proper fuses have been installed, the lines are the correct size, equipment placement is proper, and a proper evacuation has been preformed. The installation directions should be checked to verify the installation was made according to the manufacturer's instructions.

CAUTION

Before any air conditioner can be properly charged, the airflow must be properly set. This means airflow across the evaporator must be set to the manufacturer's specifications. (Usually 400 CFM/Ton for A/C, and 450/Ton for heat pumps)SEE SECTION 6

Airflow should always be set prior to system start-up. A good time to set the airflow is usually while the system is being evacuated. Airflow cannot and must not be set by measuring the temperature drop across the evaporator coil. It must be set utilizing a method that measures the actual CFM (Cubic Feet per Minute of air) across the coil. Using a capture hood and setting the airflow to meet register requirements will not do the job. The capture method does not verify airflow across the coil. It does not take into account leakage that is present in all ducting systems. In order to verify proper total system operation, the airflow at the coil and the registers must be verified. If the registers do not have the required airflow after it is set across the coil and the system is balanced, the duct system must be properly sealed.

The most accurate way to measure and set exact airflow across the evaporator in with the mini-vane anemometer. If this is not possible, a quick way to verify approximate airflow across an evaporator coil is using the pressure drop method and a manufacturer's chart. The manufacturer has spent a considerable amount of money to document these measurements. If other methods are utilized, care must be taken to assure that air has not leaked in or out ahead of the point the measurements are being taken. If exact measurements are desired, and a mini-vane is not used, the air density must be considered and the standard air formula constants adjusted to compensate for density outside of standard air. It is imperative the airflow across the coil is correct. If the airflow is too high or to low it will adversely affect the system operation.

After airflow has been set, the system refrigerant charge must be verified. A standard condenser comes with enough refrigerant charge to operate with a 25' refrigerant line set and a matched evaporator coil. However, even if the installation is standard, the charge may have to be adjusted.

In order to properly charge a refrigeration system the type of metering device must be verified. Different types of metering devices require different measurements to be made. Some manufacturers have special charging requirements that should be followed. In general, physics is physics and technicians will find that almost all air conditioning systems operate with similar characteristics. The physical and chemical laws that govern science do not change. Energy transfer is a function of time, temperature difference and turbulence (mixing). Since the time and turbulence are a factor of the airflow (set at a nominal 400 CFM/Ton) the operating characteristics will be almost identical across the board.

A common problem among service technicians is charging refrigeration equipment during low ambient conditions. With a digital manifold set (Refrigeration Analyzer) like the Testo 523, and an accurate wet bulb thermometer/hygrometer like the Testo (605-H2) it is possible and easy to accurately charge air-conditioning systems at ambient temperatures as low as 55° F outdoor air, with indoor wet bulb temperatures as low as 50° F. Below 70° F indoor air temperature, the wet bulb temperature must be used. With low indoor ambient temperatures, wet bulb temperature is required because wet bulb takes into account the total heat in the air. There must be enough heat (latent and sensible) in the air to evaporate the refrigerant in the evaporator coil at a rate equal to the rate it is being fed into the evaporator coil or the evaporator will become flooded (overfilled with liquid refrigerant).

CAUTION

It is imperative that cap tube systems are properly charged. A few ounces of refrigerant can drastically affect the operational characteristics of an evaporator using a capillary cap tube or other fixed type metering device. In order to understand system charging, a few things must be known, starting with the basics.

Refrigerant has three states in the refrigeration system.

- Saturated: a mixture of liquid and vapor
- Superheated: refrigerant vapor with measurable heat added above its saturation temperature

- Sub cooled: refrigerant liquid at a temperature below the saturation temperature

Superheat is measured to assure that the evaporator is operating at its maximum efficiency, and that liquid refrigerant is not going to enter the compressor. With a fixed metering device the superheat will vary with the load and the ambient conditions, with a TXV the superheat will remain constant, provided the load is not way above or below the operating conditions.

Subcooling is measured to assure that the expansion device has a solid column of liquid fed to it assuring that metering device will be able to control the load at its peak efficiency. With a TXV the subcooling will follow a manufacturer's curve based on a given set of operating conditions, or proper equipment subcooling will be listed on the manufacturer's equipment tag. With a fixed metering device the subcooling is not often measured, as the system is charged from a superheat curve. The subcooling will be a function of the refrigerant in the evaporator.

When charging a refrigeration system, a charging calculator should be used to assure the correct charge. One manufacturer's chart will work with any brand of equipment provided the same style metering device and the same nominal airflow are common between them. Manufacturers can have different subcooling requirements for different types of condensers, but 8-10° F subcooling is normally the standard.

Trane and Carrier Charging Calculators

Steps for proper charging:

1. **Inspect filters, evaporator coils, condensers coils and blower for dirt and clean if needed. If condenser is washed, let it dry before charging!!!**
2. Make sure evaporator airflow is correct. *(400 CFM/Ton AC 450 CFM/ton Hp)*
3. Determine type of refrigerant.
4. Determine type of metering device.

5. Measure indoor and outdoor ambient air conditions. (wb and db)
6. Determine proper superheat or subcooling. (Use manufacturer's chart if available.)
7. Attach Refrigeration System Analyzer (Recording manifold gauge set) to service valves.
8. Attach temperature probe. (To suction line for superheat measurement, to liquid line for subcooling measurement)
9. Verify refrigerant selection in manifold.
10. Charge directly by superheat of subcooling.
11. Verify system pressures and saturation temperatures are within manufacturer's design criteria if desired.

9 Maintaining the sealed system and other maintenance considerations:

There is no reason to ever to put gauges on a sealed system after the initial installation unless a problem with the mechanical refrigeration circuit is suspected. The refrigerant charge can be checked very accurately without gauges using a quality thermometer, and manufacturer's charging chart. The capacity in BTUh can be calculated determining if the unit is working at or near capacity with a Psychrometric chart, a digital thermometer, and a digital humidity stick, along with airflow as calculated by utilizing one of the methods previously described.

Prior to testing any system, make sure the filters condenser and evaporator and blower are clean. Verify the system airflow is within the desired range required by the manufacture.

The Air Conditioning and Refrigeration Institute (ARI, www.ari.org) defines the standards for air-conditioning design. All equipment in the ARI directory is rated under the same conditions. Design conditions are generally considered to be:

ARI testing Standards:	**Normal Design Conditions:**
95° F Outdoor temperature	95° F Outdoor temperature
80° F Indoor temperature	75° F Indoor temperature
50% Relative humidity	50% Relative humidity

At these conditions almost all standard efficiency air conditioners operate with a 40° F evaporator coil temperature and at 125° F condensing temperature. Information on other types of systems can be referenced in the equipment design section in the following pages. Your distributor or the manufacturer can tell you at what conditions the equipment is rated. For the rest: physics is physics and the rules don't change.

Remember the temperature drop across a coil will vary with the latent load (humidity). The higher the humidity, the more cooling energy goes to converting water vapor (humidity) to water. The drop can fall within a range of 16° to 24° degrees with ease. Setting the airflow is easy. There are several ways to do so. The easiest way is with a Mini Vane anemometer.

Remember the airflow should be 400 CFM per ton. The numbers on the manufacturer's tag indicate the BTUH rating and are converted to CFM for your convenience below.

012 (12,000 Btuh) = 400 CFM
018 (18,000 Btuh) = 600 CFM
024 (24,000 Btuh) = 800 CFM
030 (30,000 Btuh) = 1000 CFM
036 (36,000 Btuh) = 1200 CFM
042 (42,000 Btuh) = 1400 CFM
048 (48,000 Btuh) = 1600 CFM
060 (60,000 Btuh) = 2000 CFM

Checking the charge without gauges is based upon your understanding of the design operation of the equipment. Once understood, a technician can calculate without gauges what the suction and liquid line temperatures should be just as accurately as if gauges were used. **If you do not know how the system was designed to operate, there is no need to hook up gauges**. **The information that you will get will have no more value than the line temperature alone.**

To further understand checking the charge without gauges let's work from design conditions. As said above the indoor temperature was 75° F and the coil temperature was 40° F. The design temperature difference is 35° F (75 – 40 = 35). ***This temperature difference will stay the same under all load conditions at the rated CFM.*** The temperature difference is dependant upon the manufacturer's design. A high efficiency evaporator is larger, and the refrigerant may boil at a temperature difference of 30° or 45°F when the space temperature is 75°F. If not given by the manufacturer, the design temperature difference can be calculated and recorded during the installation provided the airflow and the charge are set correctly using the manufacturer's data. This practice is commonly referred to as benchmarking. The exact boiling temperature of the refrigerant depends upon the manufacturer, and how large physically the evaporator coil is. As SEER ratings change, we can expect to see the operation of the equipment change, and proper charging techniques will become more critical than ever. Keep this point in mind for later.

1) Measure the system RA (return air temperature) Wet Bulb and Dry Bulb and record it.
2) Measure the (ODA) outdoor air temperature and record it.
3) Using a charging calculator or charging chart, determine the required superheat if fixed orifice or cap tube.

4) Measure supply air wet bulb and dry bulb temperatures. (Allow operation for 10 minutes or longer.)

The return air dry bulb temperature minus the design temperature difference equals the saturation temperature of the evaporator coil. Add the required superheat, and you have the required suction line temperature. If the temperature is +/- 2°, the charge is ok.

In the system described above: R22 split system, suction line temperature measured at the evaporator coil outlet.

75°F RA - (35° F design temp difference) = 40° F evaporator coil
40° F + (8-10° F superheat) = 48-50° F suction line temperature.
+/- 2° F = 46-52° F acceptable line temperature range

If the system falls outside of the 2° range, it's time for further investigation.

It's probably time to hook up the gauges, but again, what should the pressure be?

While from the example, the saturation temperature of the air-conditioning evaporator coil is 40°F. This corresponds to a gauge pressure of 68.5 psig. The high side pressure corresponds to 120° F saturation temperature or 278 psig.

The superheat using a charging calculator should be 8-10° F. If the metering device were fixed the superheat would be 10° F meaning the suction line temperature would be 48-52° F. If the line is too cold, or to hot, verify conditions that were used in the superheat calculation, if the humidity is low, the load will be low also. Make sure the system was installed with matched components; cooling systems are designed to operate with matched components to operate within design parameters, and to reach their rated efficiency. A mismatched system may cool, but that doesn't mean it will cool efficiently or effectively.

With fixed orifice systems the capacity of the evaporator goes down as the superheat increases and the evaporator capacity goes up as the superheat decreases. The only time the evaporator will operate at its designed capacity is when the superheat setting is between 8 to 12° F. Some manufacturers provide tables to calculate the actual Btuh output for their systems under differing load conditions.

Look at the ARI equipment directory to see how the equipment was rated for the evaporator coil that is installed. This information is available from your distributor. Sometimes systems are designed specifically to remove latent or sensible heat, and the design temperature difference will change. Remember, 400 CFM per ton is the nominal airflow; lower air flow will give a higher temperature difference, due to the colder coil temperature, and higher airflow the opposite. If the system requires an airflow that is more or less than the design nominal, (i.e. Florida where a lower fan speed might be used to control humidity) you would use a different design temperature difference.

Don't forget, you will only have to do a lot of these things once. Airflows do not change substantially with proper maintenance, the components won't change, and the system is a sealed system. If this information is documented after the initial installation or service, it will become an invaluable record, and documentation of proper performance for you and your customer.

The testo 523/556/560 along with a few other digital tools will not only allow you to set up equipment with laboratory accuracy, it will also decrease your time for service, reduce callbacks, increase professionalism and provide a service to your customers that exceeds anything that your competition is currently offering. As a service tech, manufacturer's rep, maintenance technician, or lab test technician, you will have a window into the system allowing you to see what you haven't been able to see before. You will be able to more accurately diagnose problems, spot trends, and see what you have been missing. Technology can make your results better and your life easier.

10 Air Conditioning System Design

Measurements on their own mean nothing without knowledge of the design operation. In other words, why would you ever make a measurement with out having knowledge on some level of what that measurement value should be? In order to understand the task at hand it is important to have a starting place or foundation. For our purposes we will start with system design.

All manufacturers of quality equipment have their systems tested and efficiency verified by ARI, or another independent testing laboratory. Units having an energy guide label have been tested, and their efficiency can only be guaranteed if the components are matched, the system refrigerant charge is correct, the airflow is correctly set, and the system is installed per the manufacturer's instructions including proper sizing of the equipment.

To achieve the desired efficiency, all manufacturers design their equipment to operate at it rated capacity at one set of conditions at its peak performance. These conditions are known as the **ARI Standard Conditions** and are as follows.

Indoor air 80° **Humidity 50%** **Outdoor air 95°**

All equipment listed in the ARI directory operates at rated capacity under these conditions. Because the ARI standard conditions are at the high end of the normal range for human comfort, **Standard Operating Conditions**, or common operating conditions have been established as design conditions for the equipment in the field.

Indoor air 75° **Humidity 50%** **Outdoor air 95°**

Under these conditions the equipment can have a slightly lower operating capacity, and the equipment will operate with different operating characteristics. These are the conditions that we will focus on for the remainder of the manual. Along with the standard operating conditions, conditions for airflow and coil temperatures and operating range have also been established.

Note: Manufacturers offer several grades of equipment to meet different consumer needs and to be competitive in the market. Some manufacturers offer only one grade of equipment, while others offer all three. Grade and efficiency do not go hand and hand; the materials of construction for low-grade and high-grade equipment are the only difference. The efficiency will be the same. The three grades are:

1. **Economy Grade:** Currently 13 SEER
2. **Standard Efficiency:** Currently 13 SEER
3. **High Efficiency, or Ultra High Efficiency** Currently considered to be 12 SEER or higher, can go up to 20+ SEER

All manufacturers of these grades of equipment design them for a nominal 400 CFM of airflow per ton of cooling, and 450 CFM/ton for heat pumps.

STANDARD EFFICIENCY EQUIPMENT (R-22)

- Standard size evaporator
- Standard size condenser
- Fixed orifice, cap tube, or piston for metering device.
- At design operating conditions
- Indoor air 75°
- Humidity 50%
- Outdoor air 95°

1. The evaporator is designed to be 35° colder than the return air
2. The condenser is designed to be 30° warmer than the outdoor passing over it.
3. Refrigerant in the evaporator will be boiling at 40° F
   (75° indoor air - 35° design temp difference = 40° F Saturation Temperature)
4. Refrigerant in the condenser will be condensing at 125° F
5. *(95° outdoor air + 30° design temp difference = 125° F Saturation temperature)*
6. Evaporator airflow is at a nominal 400 CFM per ton
7. Measured superheat should be 8-10° F
8. Measured subcooling should be 6-8° F
9. Using R-22, Suction pressure should be 68.5 PSIG (+/- 2 PSIG)
10. High side pressure 278 PSIG (+/- 2 PSIG)
11. Suction line temperature should be 40°saturation + 8-10°superheat = 48-50° F
12. Liquid line temperature should be 125° sat – (6-8°) subcooling = 119-117° F

Note:

Always refer to manufacturer's specifications if possible.

HIGH EFFICIENCY EQUIPMENT (R-22)

- Standard size evaporator
- Larger condenser
- Thermal Expansion Valve (TXV) for metering device
- At design operating conditions
- Indoor air 75°
- Humidity 50%
- Outdoor air 95°

1. The evaporator is designed to be 35° colder than the return air
2. The condenser is designed to be 25° warmer than the outdoor passing over it.
3. Refrigerant in the evaporator will be boiling at 40° F
   (75° indoor air - 35° design temp difference = 40° F Saturation Temperature)
4. Refrigerant in the condenser will be condensing at 120° F
   (95° outdoor air + 25° design temp difference = 120° F Saturation temperature)
5. Evaporator airflow is at a nominal 400 CFM per ton
6. Measured superheat should be 8-10° F
7. Measured subcooling should be 6-8° F
8. Using R-22, Suction pressure should be 68.5 PSIG (+/- 2 PSIG)
9. High side pressure 259.9 PSIG ** (+/- 2 PSIG)
10. Suction line temperature should be 40°saturation + 8-10°superheat = 48-50° F
11. Liquid line temperature should be 120° saturation – (6-8°) subcooling
    = 114-112° F

** The lower discharge pressure provides a smaller pressure difference across the compressor, and requires less energy to operate making the system more efficient.

The higher efficiency comes at the cost of poor operation when operated in low ambient conditions. Some manufacturers have incorporated a two-speed condenser fan to rectify this problem. Even so a two speed motor and the control to operate it cost more up front. The efficiency up grade will pay for itself.

Notes:
Always refer to manufacturer's specifications if possible.

ULTRA HIGH EFFICIENCY EQUIPMENT (R-22)

- Larger size evaporator
- Larger condenser
- Thermal Expansion Valve (TXV) for metering device
- At design operating conditions
- Indoor air 75°
- Humidity 50%
- Outdoor air 95°

1. The evaporator is designed to be **30° colder** than the return air

2. The condenser is designed to be **20° warmer** than the outdoor passing over it.

3. Refrigerant in the evaporator will be boiling at 45° F
(75° indoor air - 30° design temp difference = 45° F Saturation Temperature)

4. Refrigerant in the condenser will be condensing at 120° F
(95° outdoor air + 20° design temp difference = 115° F Saturation temperature)

5. Evaporator airflow is at a nominal 400 CFM per ton

6. Measured superheat should be 8-10° F

7. Measured subcooling should be 6-8° F

8. Suction pressure should be 76 PSIG (+/- 2 PSIG)

9. High side pressure 243 PSIG ** (+/- 2 PSIG)

10. Suction line temperature should be 45°saturation + 8-10°superheat = 53-55° F

11. Liquid line temp. should be 115° saturation – (6-8°) subcooling= 109-107° F

** The lower discharge in combination with high suction pressure provides a smaller pressure difference across the compressor, and requires less energy to operate making the system more efficient.

The higher operating efficiency comes at the cost of lower latent heat capability, this system may not dehumidify as well. It will also incorporate some of same the controls that the high efficiency equipment will incorporate.

Notes:

Always refer to manufacturer's specifications if possible.

HIGH EFFICIENCY EQUIPMENT (R-410A)

- Standard size evaporator
- Larger condenser (Significantly larger than comparable R-22 unit.)
- Thermal Expansion Valve (TXV) for metering device
- At design operating conditions
- Indoor air 75°
- Humidity 50%
- Outdoor air 95°

1. The evaporator is designed to be 35° colder than the return air

2. The condenser is designed to be 25° warmer than the outdoor passing over it.

3. Refrigerant in the evaporator will be boiling at 40° F
4. *(75° indoor air - 35° design temp difference = 40° F Saturation Temperature)*

5. Refrigerant in the condenser will be condensing at 120° F
   (95° outdoor air + 25° design temp difference = 120° F Saturation temperature)

6. Evaporator airflow is at a nominal 400 CFM per ton

7. Measured superheat should be 8-10° F

8. Measured subcooling should be 6-8° F

9. Using R-410A, Suction pressure should be 118.9 PSIG (+/- 2 PSIG)

10. High side pressure 416.4 PSIG ** (+/- 2 PSIG)

11. Suction line temperature should be 40°saturation + 8-10°superheat = 48-50° F

12. Liquid line temperature should be 120° saturation – (6-8°) subcooling
    = 114-112° F

** The lower discharge pressure provides a smaller pressure difference across the compressor, and requires less energy to operate making the system more efficient.

The higher efficiency comes at the cost of poor operation when operated in low ambient conditions. Some manufacturers have incorporated a two-speed condenser fan to rectify this problem. Even so a two speed motor and the control to operate it cost more up front. The efficiency up grade will pay for itself.

It should be noted: As far as operating conditions are concerned, the only difference in operation between R-22 unit and R-410a units is the operating pressures.

Notes:
Always refer to manufacturer's specifications if possible.

ULTRA HIGH EFFICIENCY EQUIPMENT (R-410A)

- Larger size evaporator
- Larger condenser (Significantly larger than comparable R-22 unit.)
- Thermal Expansion Valve (TXV) for metering device
- At design operating conditions
- Indoor air 75°
- Humidity 50%
- Outdoor air 95°

1. The evaporator is designed to be **30° colder** than the return air
2. The condenser is designed to be **20° warmer** than the outdoor passing over it.
3. Refrigerant in the evaporator will be boiling at 45° F
   (75° indoor air - 30° design temp difference = 45° F Saturation Temperature)
4. Refrigerant in the condenser will be condensing at 120° F
   (95° outdoor air + 20° design temp difference = 115° F Saturation temperature)
5. Evaporator airflow is at a nominal 400 CFM per ton
6. Measured superheat should be 8-10° F
7. Measured subcooling should be 6-8° F
8. Using R-410A, Suction pressure should be 130.7 PSIG (+/- 2 PSIG)
9. High side pressure 389.6 PSIG ** (+/- 2 PSIG)
10. Suction line temperature should be 45°saturation + 8-10°superheat = 53-55° F
11. Liquid line temperature should be 115° saturation – (6-8°) subcooling
    = 109-107° F

** The lower discharge in combination with high suction pressure provides a smaller pressure difference across the compressor, and requires less energy to operate making the system more efficient.

The higher operating efficiency comes at the cost of lower latent heat capability, this system may not dehumidify as well. It will also incorporate some of same the controls that the high efficiency equipment will incorporate.

Notes:
ALWAYS REFER TO THE MANUFACTURER'S SPECIFICATIONS IF POSSIBLE.

After considerable testing, we have found almost all equipment manufacturers have identical evaporator operating characteristics depending on their classification. This is due to the design criteria governed by design conditions in the ARI and industry procedures for testing. At a nominal CFM, all evaporators have to have similar operating characteristics to remove the same amount of heat from the same amount of air under the same load conditions. It comes down to physics, time, temperature difference and turbulence. In order to remove the same amount of heat (using refrigerants with identical saturation temperatures and the same airflow), the refrigerant boiling temperature must be the same across the board. Therefore, for the purposes of heat transfer, the refrigerant type (R-12, R-22, R-410A) does not matter as long as the saturation temperature remains the same.

Condensers, on the other hand, do not always follow conventions. Manufacturers will differ in the compressor selection, metering device, required subcooling and temperature rise according to their own design to meet the capacity and energy use requirements. In practice is best to benchmark the condenser performance at installation if the manufacturer's information is not available to make future evaluation of the condenser performance.

After initial installation and system commissioning, there is no reason to install gauges creating the possibility of leaks, loosing refrigerant from installing and removing hoses or otherwise accessing the sealed system violating the system integrity. All information pertaining to the sealed system performance can be accurately evaluated using temperatures alone with knowledge of design. A thorough understanding of system design and field practice of benchmarking systems will save time, increase equipment life, and reduce refrigerant emissions.

11.1 TERMS AND DEFINITIONS - THAT DEAL DIRECTLY WITH THE REFRIGERATION SYSTEM

Refrigerant: The fluid in the refrigeration system used to transfer heat into the evaporator, and out of the condenser. Refrigerants have qualities like low boiling points, and low or no toxicity that make them advantageous in the refrigeration system. Refrigerant is sealed in the system, it never wears out, and it should never leak out. However, improper maintenance, poor or no service or component breakdowns can impact the “health” of the refrigerant.

Refrigerants have three states:

- **Saturated:** Refrigerant liquid and vapor existing together.
- **Superheated:** Refrigerant vapor heated above its saturation temperature.
- **Subcooled:** Refrigerant liquid cooled below its saturation temperature.

All refrigerants have different saturation temperatures and pressures. These properties can be found on PT charts (pressure - temperature charts) these properties are also automatically calculated with a Testo refrigeration analyzer.

If the refrigerant is condensing or boiling, the temperature pressure relationship holds true.

The only place that the P.T. relationship will hold true is in the evaporator, condenser, and the receiver.

For **every** saturation temperature, there is a corresponding saturation pressure.

RESTATED

For every temperature where a mixture of liquid and vapor exists, there is an exact pressure.

1. Compressor: The compressor is a VAPOR pump; its function is to *create a pressure difference.* It must be sized to remove the vapor refrigerant from the evaporator at the proper rate, and to move it at the proper velocity through the system. Refrigerant enters as superheated vapor, and leaves as highly superheated vapor.

2. Condenser: The component in the refrigeration system that *rejects heat*. Highly superheated vapor from the compressor enters the condenser where it is de-superheated, saturated to a liquid, (rejecting a large quantity of heat) and then subcooled

3. Metering Device: A valve or fixed orifice that meters refrigerant into the evaporator. Its function is to *create a pressure drop*, and in turn a temperature drop.

4. Evaporator: The component in the refrigeration system that *absorbs heat*. Liquid refrigerant enters the evaporator, and boils or vaporizes absorbing large quantities of latent and sensible heat.

5. Thermal Expansion Valve: (TXV or TEV) a metering device that *maintains constant superheat*, and controls the evaporator load over a wide range of conditions. Usually maintains 8-12° F of superheat at the tail end of the evaporator.

6. Capillary Tube: a metering device that controls refrigerant flow by a pressure drop. Usually a copper tube with a very small inside diameter. The diameter and length determine how much liquid will pass through the tube at any given pressure drop. (Does not control superheat)

7. Fixed Bore Metering Device: (Piston) A type of metering device that determines flow by pressure drop only. The piston must be matched to the condensing unit requirements. (Does not control superheat)

8. Suction Line: (Vapor line, insulated large line) connects the evaporator to the inlet of the compressor.

9. Discharge line: (hot gas line,) connects the compressor outlet to the inlet of the condenser.

10. Liquid Line: connects the outlet of the condenser to the inlet of the metering device.

11. Distributor: Connects the outlet of the metering device to the inlet of the evaporator, on multi circuit coils (multiple tubes).

12. Compound Gauge: A gauge that reads pressures above atmospheric pressure in PSIG, and below atmospheric pressure in inches of Mercury column ("Hg) (Usually Blue)

13. Pressure Gauge: A gauge that reads pressures only above atmospheric pressure in PSIG. (Usually Red)

11.2 Terms and Definitions - THAT DEAL DIRECTLY WITH PROPERTIES OF AIR

1. Air Conditioning: A system that can control the temperature (heating or cooling), humidity, and cleanliness of the air (In residential practice refers primarily to cooling)

2. Humidity: The concentration of moisture in the air.

3. Relative humidity: The amount of humidity the air is holding verses what it could hold at any given temperature.

4. Dehumidify: To remove moisture from the air. (Air must be cooled below its saturation point to condense and remove moisture, then it must be reheated to expand

5. Humidify: To add humidity to the air.

6. Dew point: The exact temperature at which moisture drops out of the air and begins to form on an object. (Air cooled below its dew point will start to loose its moisture).

7. Dry Bulb: Temperature measured using a standard thermometer. (Sensible temperature)

8. Wet bulb: The air temperature used to evaluate humidity and temperature or total heat, (heat energy present in the air and the latent heat in the humidity). Originally obtained by wrapping a wet cotton wick around a dry bulb thermometer and passing the air to be sampled at a prescribed rate across the sock. The rate of evaporation, hence the humidity in the air, will lower the temperature of the wet wick. Today it is instantly calculated with a humidity stick.

9. Sling Psychrometer: A device with two thermometers, one dry bulb, and one wet bulb, used for verifying the wet bulb and dry bulb conditions of the air. These readings are used to calculate the relative humidity.

10. Digital humidity Stick: A device used to replace a sling psychrometer, reads conditions instantly and directly without analog errors.

11. Enthalpy: Total heat energy contained in a sample of air (sensible and latent heat energy).

12. Air density: The weight of a cubic foot of air (Standard air weighs o.075 LBS/cubic foot at 75° and 50%RH at sea level)

13. Pressure Drop: Measure of static pressure loss across a coil, heat exchanger, or filter. Measured in inches of water column.

14. T.E.S.P = Total External Static Pressure, the pressure drop across an appliance from the return to the supply side. If it is a furnace, it is measured before the evaporator coil. If an air handler, it is measured across the entire appliance from supply to return.

15. Atmosphere: Air composed of
    i. 78% Nitrogen
    ii. 20.9 % Oxygen
    iii. ~1% Trace Gasses

16. Atmospheric Pressure: The weight of the air that makes our atmosphere. (14.7 PSIA at sea level) This number changes with altitude and atmospheric conditions

17. PSIG Pounds per square inch gauged or relative to local atmospheric conditions, a number which may change depending on altitude and atmospheric conditions (PSIA – atmospheric)

18. PSIA Pounds per square inch absolute, a fixed number relative to vacuum, the same anywhere in the world,

19. Vacuum: a measure of pressure with some or the entire atmosphere removed. (Perfect Vacuum = -14.7 PSIG, 0 PSIA, 29.92"hg, 0 microns)

20. Micron a unit of length equal to 1/1000th of a millimeter, also used to indicate the depth of a vacuum, lower microns equal deeper vacuums

21. There are 25,400 microns per inch of mercury

22. Micron Gauge: A digital or analog instrument used to convert units of pressure to microns

23. 500 microns or ½ mm hg is an acceptable level of vacuum

24. Digital Manometer: An instrument used to check very low vapor pressures in inches of H_20 (usually used to check gas pressures in a manifold or air pressures in a duct)

Laws of Humidity Transfer:

- Humidity will always travel from high pressure to low pressure, and from humid to dry.
- The rate of humidity transfer depends upon the pressure difference between the two zones, and the amount of water that each is holding.

Notes:

11.3 Terms and Definitions - THAT DEAL DIRECTLY WITH HUMAN COMFORT

1. The human body generates heat. Our comfort depends upon controlling how much heat our bodies reject at any given time.

2. The human body rejects heat in three ways:

   - Radiation: Impacted by controlling the surrounding air and objects temperatures

   - Evaporation: (Sweating) Impacted by controlling the relative humidity

   - Convection: Impacted by controlling air movement

   ** Conduction is not normally considered, because our bodies are usually insulated from the objects we touch by our clothing, and our shoes. A small amount of heat is transferred in this way.

3. The design conditions for human comfort are:
   - 70° to 80° F
   - 40 to 60% RH
   - Airflows low enough that do not create objectionable air movement or noise.

4. In the summer we can be comfortable with warmer temperatures because the convective air currents are cool. The air coming out of the supply register is 55-65°F. Heat is traveling out of the body into the cool air making us feel comfortable.

5. In the winter the convective air currents are warmer, 95-145° F from the furnace
   This makes heat travel into the body from the warm air making us again comfortable.

6. If heat travels into or out of the body too quickly, we become either too hot or too cold respectively.

7. If the humidity is too high, the body is not able to cool by evaporation.

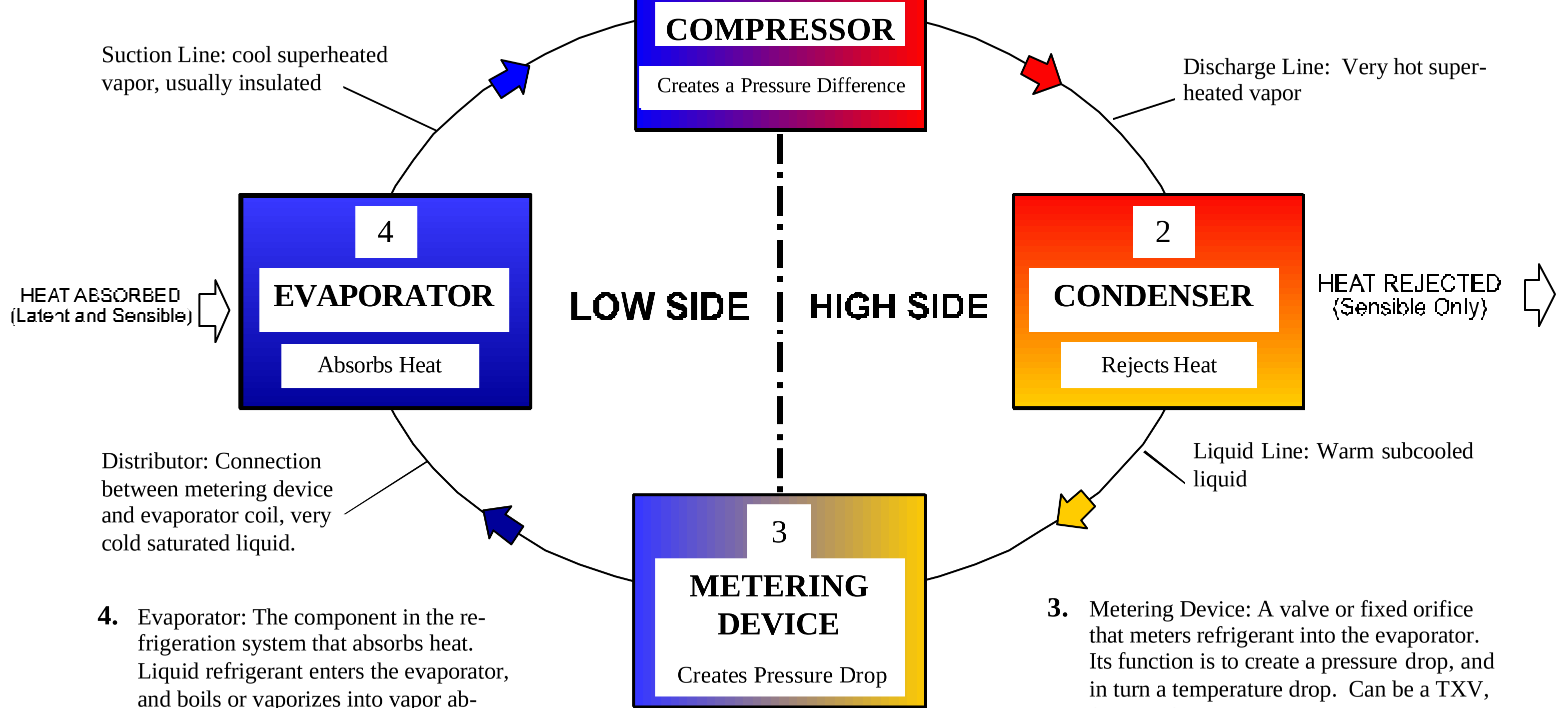
8. If the humidity is too low, excessive evaporation will chill the surface of the body.

Notes:

The Basic Refrigeration System

1. Compressor: The compressor is a VAPOR pump; its function is to create a pressure difference. It must be sized to remove the vapor refrigerant from the evaporator at the proper rate, and to move it at the proper velocity through the system. Refrigerant enters as superheated vapor, and leaves as highly superheated vapor.

2. Condenser: The component in the refrigeration system that rejects heat. Highly superheated vapor from the compressor enters the condenser where it is de-superheated, saturated to a liquid, (rejecting a large quantity of heat) and then subcooled



4. Evaporator: The component in the refrigeration system that absorbs heat. Liquid refrigerant enters the evaporator, and boils or vaporizes into vapor absorbing large quantities of heat in the process.

3. Metering Device: A valve or fixed orifice that meters refrigerant into the evaporator. Its function is to create a pressure drop, and in turn a temperature drop. Can be a TXV, fixed orifice, or a capillary tube.

UNDERSTANDING THE BASIC COMPONENTS

13 THE COMPRESSOR: THE HEART OF THE SYSTEM

The compressor is what creates the pressure difference, and thus moves the heat load. The heat load is the sensible and latent heat absorbed in the evaporator, and increased in temperature and pressure to reject it from the condenser.

There are six common types of compressors:

1. **Reciprocating:** (Standard A/C compressor)
2. **Scroll:** New Style A/C compressor, can handle small amounts of liquid without damage
3. **Rotary:** common in window air conditioners and refrigerators
4. **Open**: Older belt and direct drive applications
5. **Centrifugal:** Large low pressure commercial/industrial units
6. **Screw** Large tonnage commercial

There are three main types of compressor assemblies:

1. Fully hermetic (tin can)**
2. Semi hermetic **
3. Open (Belt drive or close coupled)

** Refrigerant Cooled

1. The compressor, of any type, performs two basic functions.

    a. It creates a pressure difference by removing the vapors generated in the evaporator at a given rate to create and maintain the proper temperature difference. (By controlling the low side pressure.)
    b. It must compress the low pressure, low temperature, superheated gas to a high pressure, high temperature superheated gas that is at a temperature above the condensing temperature.

2. The compressor pumping capacity is proportional to the load across the evaporator and condenser coils

3. An increase in the load at the evaporator coil would cause the liquid to boil faster, and thus generate more vapors. This increase in the volume of vapor will raise the low side pressure. The increase in low side pressure would increase the density of the refrigerant vapor and thus the capacity of the compressor.

4. A decrease in the load at the evaporator coil would result in less liquid boiling in the coil, thus lower vapor density. This decrease in the volume and density of vapor will lower the low side pressure. The reduced low side pressure would reduce the pumping capacity of the compressor.

5. A higher outdoor temperature or a dirty condensing coil would raise the high side (head or discharge) pressure. The higher head pressure would reduce the pumping capacity of the compressor.

6. A lower outdoor temperature would cause a reduction in the head pressure and the pumping capacity of the compressor would increase.

7. The amp draw of the compressor will reflect how much work the compressor is doing. (More work = higher amps, less work = lower amps.)

8. The compressor amps will always follow the low side pressure if the valves are operating properly. If the low side pressure is higher than it should be for the conditions under which it is operating, and the amps are low, the compressor valves are bad.

9. The high side pressure will reflect what is happening on the low side. This is because the amount of vapor being generated on the low side is what is compressed and sent to the high side.

10. The suction vapor is used to cool the compressor motor windings. The vapor should never be above 65° F for extended periods of time or compressor damage will result.

11. The refrigerant line that carries the superheated high pressure, high temperature from the outlet of the compressor to the inlet of condenser is called the hot gas line, or the discharge line. Heat from the evaporator + heat energy from the compressor are discharged into the condenser.

12. The discharge line should reach temperatures of 140° and 190° F. It should never operate above 200° F for extended periods of time due to deterioration of the compressor oil resulting in lubrication failure. .

13. A cool or cold discharge line is an indicator that liquid or saturated refrigerant is entering the compressor. Liquid flood back can cause severe damage to the compressor.

14. A discharge line that gets cooler as the compressor first starts is an indication that refrigerant is migrating into the evaporator, or the compressor crankcase during the off cycle, a crankcase heater and/or a drop solenoid may be needed to correct these problems

15. All standard compressors contain oil to lubricate the bearings.

16. The oil will never go bad if the system remains sealed, and the temperatures are not excessive for long periods of time.

17. It is imperative that the compressor does not have too much oil, as the oil circulates with the refrigerant in the system, the oil must be returned to the

compressor in small amounts or oil slugging could result. (Oil slugging is the passing of liquid droplets of oil through the compressor.)

18. Oil acts as an insulator. Excessive oil will lower system efficiency by not allowing the refrigerant to conduct heat as readily. Excessive oil can also cause oil slugging.

19. Remember, suction vapor should always enter the compressor below 65°F and always leave below 200°F, if the suction pressure is high, and the compressor amps are low, the valves are bad. If the unit has a sight glass, the oil level can range from barley visible to ¾ full without damaging the compressor. The oil level will change as the system operates because the oil is out in the system. See manufacturer's requirements for oil level requirements.

Notes:

14 THE CONDENSER: THE HEAT REJECTOR

Condenser: The component in the refrigeration system that rejects heat. Highly superheated vapor from the compressor enters the condenser where it is de-superheated, saturated to a liquid, (rejecting a large quantity of heat) and then subcooled

1. Residential air conditioning systems primarily use air-cooled condensers.

2. The three things that must happen to the refrigerant in the condenser are:

   The discharge vapor must be:
   1. De-superheated
   2. Saturated
   3. Subcooled

3. The condenser is located outdoors and uses outdoor air to cool the superheated hot vapor that is discharged into it from the compressor.

4. The amount of gas entering the condenser is related to the amount of gas being generated in the evaporator. (How much liquid refrigerant is boiling in the evaporator.)

5. The temperature of the gas entering the condenser is determined by:

   a. The temperature of the gas being generated in the evaporator. (The saturation temperature in the evaporator)
   b. The superheat that the gas has as it enters the compressor.
   c. The compression ratio of the compressor
   d. The waste heat from the motor windings in the compressor.

6. The superheated, high pressure, high temperature gas enters at the top of the condenser. The hot gas temperature entering the condenser is normally between 140° to 190°F.

7. The outdoor air is brought across the condenser coil by the condenser fan. Since the outdoor air is cooler than the hot gas, and heat travels from hot to cold, heat travels from the condenser into the outdoor air.

8. As the hot gas de-superheats, and cools towards the saturation point, (condensing point) the temperature of the gas drops, while the pressure remains relatively constant (some pressure drop due to friction) the higher pressure and the lower temperature forces the gas to condense into a liquid.

9. The liquid is still warmer than the air so it continues to give off heat to the cooler air. The liquid refrigerant cools below its saturation point (condensing temperature) and becomes subcooled. (Cooled to a temperature below the condensing temperature.)

10. The amount of subcooling will vary with the efficiency of the condenser and the outdoor air temperature.

    i. A cooler outdoor temperature will give more sub-cooling. (The liquid line will be colder.)
    ii. A warmer outdoor temperature will result in less sub-cooling. (The liquid line will be warmer.)
    iii. The liquid refrigerant leaving the condenser will normally be sub-cooled between 6° to 8° during normal operating conditions.
    iv. The liquid subcooling could be as high as 28-30 degrees when the ambient temperature is low.

11. Subcooling reduces the probability the liquid refrigerant will flash (quickly evaporate) into gas in the liquid line. It also reduces the amount of flash gas that will occur when the refrigerant drops in pressure as it passes through the metering device and enters the evaporator coil.

12. Flash gas reduces the system capacity. Flash gas is the term used to describe the rapid boiling (or vaporizing) of the liquid refrigerant in an expansion device. About 25% of the liquid passing through the metering device is turned to vapor, cooling the balance of the liquid to its corresponding saturation temperature in the evaporator.

13. The system's capacity is increased by 1/2% for every 1° F of subcooling.

14. The condenser coil construction is similar to the construction of the evaporator coil. The tubing is the primary heat transfer surface and fins are added to increase the surface area of the coil. Fins can be of many different types including straight, wavy, and Spinfin ®.

15. The cleanliness of the coil is very important to the heat transfer operation of the condenser. The coil should be cleaned every spring and during the summer (especially after the cottonwood flies) to insure efficient heat transfer and lower head pressure, (high side pressure) this insures proper sub-cooling, maximum capacity, and reduced operating costs. Any heat not rejected in the condenser returns to the evaporator, lowering the system capacity.

Note: *Some manufacturers including Trane and Carrier have manufactured spilt coils, (two layers of single row coils) the split coils must be separated and washed in between to remove the dirt from the inner coil surfaces. The outside of the coil will appear to be clean, but the inside may be completely blocked.*

16. The high side pressure gage on your manifold gage set will read the pressure at which the gas is condensing into a liquid. A digital gauge set will instantly show the precise saturation temperature or alternately, the proper temperature hash marks on the manifold gauge may be read or a pressure temperature chart can be used to manually determine it.

17. Depending on the design efficiency of the condenser, the temperature difference between the outdoor air and the condensing temperature will be:

    i. 30° F warmer than the outdoor air temperature for Standard Efficiency
    ii. 25° F warmer than the outdoor air temperature for High Efficiency
    iii. 20° F warmer than the outdoor air temperature for Ultra High Efficiency

18. The subcooling is calculated by:

    a. Measure the liquid line pressure with the refrigeration system analyzer; the condensing pressure/temperature of the refrigerant.
    b. Use a digital thermometer to read the temperature of the liquid line where it leaves the condenser.
    c. Subtract the liquid line temperature from the condensing temperature. The difference between these two temperatures is the degrees of sub-cooling.

19. The high side (head or discharge) pressure will vary with the outdoor temperature and the cleanness of the coil.

    a. As the outdoor temperature goes down, the head pressure will go down.
    b. As the outdoor temperature goes up, the head pressure will go up.
    c. If the coil is dirty the head pressure will go up.
    d. If the coil is clean the pressure will be normal.

20. On a residential system that uses a fixed bore metering device the superheat will also vary with the outdoor temperature. The examples below assume that the indoor temperature remains constant.

    a. As the outdoor temperature goes down, the head pressure will go down. The lower head pressure will result in a smaller pressure difference across the metering device. This reduced pressure differential across the metering device will result in less liquid being forced through the metering device. Since less liquid will be in the evaporator coil, the superheat will go up.

b. As the outdoor temperature goes up, the head pressure will go up. The higher head pressure will result in a greater pressure difference across the metering device. This increased pressure differential across the metering device will result in more liquid being forced through the metering device. Since more liquid will be in the evaporator coil, the superheat will go down.

21. NOTE: *The compressor should not be operated when the outdoor temperature is below 55°F*

22. It is nearly impossible to properly charge refrigerant into a residential system when the outside ambient (surrounding air temperature) is below 70°F using **gauges** with the superheat or subcooling methods. During periods of low load, inaccuracies inherent with mechanical gauges make it very easy to overcharge the system. If gauges are the only tool available, the system could be charged by weight.

23. At outside temperatures below 70°F the condenser becomes very efficient. The system will show low head pressure, low suction pressure, and high superheat due to charge migration. These symptoms will appear to show that the system is undercharged. With digital gauges and real time superheat readings, pressures and temperatures can be tracked in real time allowing the technician to work confidently in ranges that would otherwise prove to be troublesome.

24. A condenser problem will affect the low side on a system using a fixed bore-metering device.

25. A high side problem (condenser problem) would be one that causes the head pressure (discharge or high side pressure) to be higher than normal for the conditions that exist.)

26. A dirty coil, inoperative condenser fan motor, restricted airflow, recirculated airflow, improper fan blade, or a heated exhaust (e.g. from a clothes dryer vent) hitting the condenser coil will all create a higher head pressure than normal.

27. Higher than normal discharge pressure or a lack of subcooling would indicate a condensing problem.

15 THE METERING DEVICE:

Metering Device: A valve or fixed orifice that meters refrigerant into the evaporator. Its function is to create a pressure drop, and in turn a temperature drop of the refrigerant.

The expansion device is the least visible component of the refrigeration system, often located inside the plenum, or evaporator cabinet. It can either be a valve, or a fixed type metering device. **It is imperative** that the type of metering device be known before the system charge in checked or adjusted as charging procedures for different types of devices are different.

The expansion device is one of the dividing lines between the high side and low side of the system (the compressor is the other) and is responsible for insuring that the liquid refrigerant metered into the evaporator is completely vaporized at the end of the evaporator coil, insuring that liquid refrigerant does not enter the compressor. A TXV will measure and adjust the superheat, while a fixed orifice is sized to operate under one set of conditions, and the superheat will vary with the load.

I) The Thermal Expansion Valve (TXV or TEV):

1. The TXV meters refrigerant into the evaporator using a thermal element to respond to, and monitor the superheat. The TXV is always looking at what it just did and is constantly making corrections to the superheat.

2. **Thermal expansion valves almost never fail!** If they do fail it is due to other system problems such as moisture, dirt, or wax. Problems with the thermal element do occur if it is kinked, damaged, or has poor contact.

3. If the superheat is too high the valve will open allowing more refrigerant into the evaporator coil, lowering the superheat.

4. If the superheat is too low, the valve will close, allowing less refrigerant into the coil and the superheat will increase.

5. **The temperature of the evaporator coil will remain constant**. The amount of refrigerant in the coil will not. The amount of heat that the vapor picks up at the end of the coil will vary with the load. The superheat will change; the pressure and temperature of the evaporator will remain the same unless the system is severely over/undercharged.

6. Raising or lowering the system superheat affects the systems' ability to transfer more or less heat energy. It changes the capacity of the evaporator coil. If the coil is more efficient, it will remove more sensible and latent heat. The temperature drop across the coil will increase.

7. The superheat spring on a balanced port TXV is set from the factory, and should never be adjusted.

8. It is good practice to ***never*** adjust a TXV superheat spring; if the valve is not maintaining proper superheat, replace the entire valve (under 5-tons).

9. On larger valves, over 5-ton capacity, the cage assembly, and the power element can often be replaced without removing the valve. This practice is desirable because it is faster and requires less invasion of the system.

10. The remote bulb mechanically attaches to the suction line near the outlet of the evaporator coil. It should always be located up-stream of the external equalizer line, as it can be affected if the TXV has an internal leak.

11. The TXV had three pressures that operate together to maintain superheat
    1) Bulb pressure, an opening pressure
    2) Superheat spring, a closing spring pressure
    3) Evaporator back pressure, a closing pressure

12. The TXV is never fully open or fully closed after the compressor has been operating for several minutes. It will throttle to maintain constant superheat

13. Any change to the load, increase or decrease, will causes the valve to hunt for a new position to control the load.

14. All metering devices operate best with a constant load, in the center of their designed operating range. The valve has the ability to operate above or below the designed capacity within reason.

15. During the off cycle, the suction line and spring pressure will overcome the bulb pressure and the valve will close.

16. Because the high and low side pressure will not equalize in the off cycle on reciprocating equipment, the compressor motor will need higher than normal starting torque. A start capacitor, in conjunction with a relay and a run capacitor is often used for this purpose.

17. Scroll compressors equalize pressure through the compressor, unless a discharge check valve is used, and do not require start assist devices.

18. The manufacturer, or a representative of the valve manufacturer should select the proper TXV application. (Internally equalized, Externally equalized, balanced port, pressure limiting, or pressure equalizing) When selecting a valve, pressure drop through the coil, coil operating temperature, liquid entering temperature and pressure, along with type of refrigerant and tonnage must be considered.

15.1 FIXED METERING DEVICES

1) Fixed Bore Metering Device: (Piston) A type of metering device that determines flow by pressure drop only. The piston must be matched to the condensing unit requirements. (Does not control superheat)

2) **For proper operation the charge is critical, 1 or 2 ounces of refrigerant can drastically change the system operation.**

3) **Manufacturers' charging charts, or a charging calculator must be used to properly charge systems incorporating these devices**

4) Fixed bore metering devices operate correctly only under one set of conditions. (8-12° F superheat) Outside of those conditions, the system efficiency will vary.

5) Fixed metering devices are slow to respond to change, sufficient time must be allowed between adding or removing charge, and checking final operating conditions. Usually 10-15 minutes per adjustment.

6) Superheat with a fixed metering device can be from 5-45 degrees F and be operating with the proper charge.

7) Care must be used in low temperatures when charging a fixed bore system because overcharging is very easily achieved.

8) If the size of the metering device is in question, the system can be pumped down to zero psig, and the size of the metering device verified. The piston has a number stamped on the brass that will identify the size. It must be sized to match the condenser.

Notes:

16 THE EVAPORATOR: THE HEAT ENERGY ABSORBER

1. Evaporator: The component in the refrigeration system that absorbs heat. Liquid refrigerant enters the evaporator, and boils or vaporizes into vapor absorbing large quantities of heat in the process. The evaporator is where the “work” is done. The “work” is the removal of heat from the air coming in contact with the coil.

2. The coil is composed of copper and aluminum fins allows more contact between the air and the heat transfer surfaces.

3. The design of the evaporator coil allows two things to happen to the refrigerant on a properly operating system.

   - The refrigerant vaporizes in the evaporator absorbing heat.
   - The refrigerant boils lowering the coil temperature below the dew point allowing the removal of humidity

4. The boiling of the low pressure, low temperature liquid refrigerant inside of the evaporator creates the system pressures.

5. The low side pressure can be converted to an exact temperature at which the liquid is boiling inside of the evaporator.

6. The air that comes into contact with the evaporator coil provides the heat and humidity (the load) to boil the low pressure, low temperature saturated liquid refrigerant.

7. The amount of heat that is available to boil the liquid refrigerant in the evaporator coil is dependent upon:

   a. The temperature of the air. (Dry bulb temperature or sensible heat load)
   b. The relative humidity of the air. (Latent heat load)
   c. The volume of the air measured in CFM (Heat quantity usually measured in pounds of air and converted to CFM)

8. The return air (Air returning back to the air handler from the conditioned spaces) will provide the “load” on the evaporator coil.

9. If the temperature of the air is below 70° F, and air does not contain enough heat (sensible and latent) to properly boil the liquid refrigerant in the coil. The saturation temperature may drop below 32° or freezing, causing ice buildup on the coil, eventually leading to low airflow and compressor flood back.

10. If the air volume (measured in CFM) is below 400 CFM per ton (12,000

BTUH) there won't be enough heat quantity to properly boil the liquid refrigerant. Under low load conditions like this liquid flood back could result.

11. The design condition ranges (heat quantity) that will insure proper operation are:

    1. 70° to 80°F dry bulb (Sensible heat load)
    2. 40 to 60% relative humidity (latent heat load)
    3. 350 to 450 CFM/Ton or 12,000 BTUH of cooling

12. If the dry bulb temperature and humidity are too low, the system will be in a low load condition. (Not enough heat to properly boil the liquid refrigerant) The saturation temperature may drop below 32° or freezing, causing ice buildup on the coil, eventually leading to low airflow and compressor flood back.

13. If the dry bulb temperature and/or humidity is too high, the system will be in a high load condition (More heat than the system was designed to handle.)

14. Humidity affects the amount of latent heat (converting the water vapor that is in the air to water, or condensate) that the system must remove.

15. As the humidity level goes up (wet bulb temperature up) the amount of dehumidifying that occurs will go up. This means more latent heat is being removed and the temperature drop across the evaporator coil will go down. (Less sensible heat change across the coil.)

16. As the humidity level goes down (wet bulb temperature down) the amount of dehumidifying that occurs will be less. This means less latent heat is being removed and the temperature drop across the evaporator coil will go up. (More sensible heat change across the coil.)

17. Humidity will also affect the superheat on a **fixed-bore** metering device system. High humidity =more superheat, low humidity = less superheat.)

18. If the airflow is too low there won't be enough heat quantity (total heat) to allow the system to work properly. The system could be under a low load even if the air is warmer than normal.

19. If the airflow is too high in the system the humidity removal will be poor and condensed water could be blown off of the coil into the ducts. *It is not common for an air evaporator to have high load due to excessive airflow, this goes back to the concepts of time, temperature difference and turbulence, if the air is going by too fast, the heat will not transfer to the coil.*

20. While the range for airflow across the evaporator coil is between 350 to 450 CFM per ton of cooling, the ideal airflow for air conditioning is 400 CFM per ton.

21. As the airflow moves from 400 CFM/ton towards the 350-CFM/ton range it will affect the latent to sensible heat cooling relationship. It will also reduce the system's sensible capacity. (More latent cooling and less sensible heat cooling)

22. As the airflow moves from 400 CFM/ton towards the 450-CFM/ton range it will affect the latent to sensible heat cooling relationship. It will also increase the system's sensible capacity. (Less latent cooling and more sensible heat cooling)

23. Since heat travels from the hot to the cold the liquid refrigerant temperature must be colder than the return air coming across the coil in order for the air to be cooled. (The standard design temperature difference between the return air and the evaporator coil is 35° F)

24. Since the rate of heat transfer is directly related to the temperature difference, air conditioning systems are designed to operate at a 35-degree F temperature difference. That temperature difference is the difference in the temperature between the liquid refrigerant boiling temperature inside of the coil and the return air temperature.

25. The temperature difference is created and maintained by the compressor capacity. The compressor pumping capacity is matched to the vapor generating capacity of the evaporator. This match will create and maintain the proper temperature difference as long as the load falls within the design range.

26. The refrigerant line that leaves the evaporator and carries the low pressure, low temperature, superheated vapor from the evaporator to the compressor is called the suction line. The suction line is normally insulated to reduce the amount of heat (superheat) that the gas will pick up before it enters the compressor, and to prevent the pipe from sweating in the conditioned space.

17 THE REFRIGERANT

The Testo 523/556/560 has several advantages when checking charging or adjusting refrigerant levels. Using Real time superheat and subcooling calculations the 523/556/560 allows the user to accurately see what is happening within the system allowing the system to be charged with laboratory accuracy in the field. Employing 30 different temperature and pressure charts, the user does not need to be concerned with having the right temperature pressure chart for the job. As new refrigerants are manufactured the 523 RSA can be updated via factory service or with the 556/560, the World Wide Web as needed. The 523/556/560 automatically calculates the bubble and dew point of Azeotrope refrigerants as superheat and subcooling calculations are done allowing the user to work with ease when working with blends. The 523 calculates the bubble/dew points for Zeotropic refrigerants at the end of all evaporation/condensation.

Definitions

1) Considered the fifth component of the refrigeration system
.
2) The refrigerant is the fluid medium that circulates within the system absorbing and rejecting heat.

3) The bulk of the refrigerant in an operating system is in the liquid line, condenser and evaporator in either liquid or saturated form.

4) Refrigerant has three states, Liquid (Subcooled) Vapor (Superheated) and Saturated (Mixture of liquid and vapor)

    a. Saturated refrigerant contains a mixture in any proportion of liquid and vapor.
    b. Superheated refrigerant is refrigerant above its saturation temperature existing only as a vapor.
    c. Subcooled refrigerant below its saturation temperature existing only as a liquid.

5) Refrigerants have a defined chemical makeup and are usually designated with an “R-number” by ASHRAE and oftentimes a color for easy identification.

6) A refrigerant absorbs heat when changing state from liquid to vapor

7) A refrigerant rejects heat when changing from vapor to liquid

8) Pure refrigerants have one pressure for each temperature where a mixture exists.

9) If the pressure on a refrigerant is dropped, the refrigerant will boil (change state from liquid to vapor) and the temperature will drop.

10) Desirable properties of refrigerants:
- Ability to carry large amounts of energy via phase change
- Safe
- Detectable
- Has good pumping characteristics
- Stable
- Mixes well with oil
- Environmentally friendly
- Low Cost

11) Refrigerant cylinders have a check valve so only refrigerant goes out (minimizing cross contamination), and a relief valve to protect the cylinder from over pressurization.

12) Although refrigerants may be nontoxic, they are heavier than air and can displace oxygen around you. If concentrations are high enough they will cause suffocation and death by oxygen deprivation.

18 Concepts, Definitions and Refrigeration Terminology

CONCEPTS, TERMS AND DEFINITIONS THAT DEAL WITH HEAT AND HEAT TRANSFER

1. Air conditioning is nothing more than moving energy, to be exact, it is moving heat energy.

2. Air conditioning moves heat from a place where it is not wanted to a place where it doesn't matter.

3. Hot and cold are relative terms, we use them to describe how something feels compared to our body temperature.

4. Cold is defined as the absence of heat. There is really only one temperature where it is cold, that is –459.67° F, or absolute zero, (all molecular motion stops) at any temperature above that a material has heat energy present.

5. Heat is energy that causes molecules to move.

6. Heat can also be defined as stored energy. Remember anything above -460° F has heat energy stored in it.

7. Heat can transfer by three methods.

   - **Conduction:** Molecule to molecule contact.

   - **Convection:** Heat transfer through a fluid medium, usually air or water.

   - **Radiation:** Heat transfer through elecromagnetic waves, heat that warms objects it hits without warming the air. The sun heats by radiation. To heat by radiation a direct line of sight is required.

8. **Sensible Heat** is heat energy that can be measured with a thermometer; the energy will cause a change in temperature without a change in state.

9. **Latent Heat** is heat energy that will cause a change in state, but it cannot be measured on a thermometer, it is often referred to as hidden heat.

10. Total Heat = sensible heat + latent heat.

11. Temperature is a measure of the kinetic energy (energy of motion) in a material.

12. BTU (British Thermal Units) is a measure of heat <u>quantity</u>.

13. One BTU is the amount of heat required to raise one pound of water 1° F.

14. BTUH is BTU's per hour. Air conditioners are rated in BTUH.

15. Enthalpy = A sum of the internal energy in a material or for our purposes Total Heat.

16. One Ton of cooling = 12,000 BTUH

17. CFM = Cubic feet per minute; CFM is often used to measure airflow. To properly function most air conditioners require 400 CFM per ton of cooling.

18. Humidity. The concentration of moisture in the air. (Takes energy to remove.)

Laws of Heat Transfer:

- Heat always travels from hot to cold
- The rate of heat transfer depends upon the temperature difference.

Time, temperature, and turbulence affect heat transfer.
In other words as air passes through a coil, the time it is in contact with the coil surface, the temperature difference between the coil and the entering air, and the redirection or turbulence of the air all affect the heat transfer.

Refrigeration Terminology

Alkyl Benzene Oil - Synthetic refrigeration oil commonly known as Zerol®.

Alternative Refrigerant - Any of a number of refrigerants or refrigerant mixtures designed to replace the current CFC or HCFC refrigerants.

Azeotrope - A mixture made up of two or more refrigerants with similar boiling points that act as a single fluid. The components of azeotropic mixtures will not separate under normal operating conditions and can be charged as a vapor or liquid.

CFC Refrigerant - CFC refers to the chemical composition of the refrigerant. ChloroFluoroCarbon indicates that the refrigerant is comprised of Chlorine, Fluorine, and Carbon. Common CFC refrigerants are R11, R12, ,R113, R114, and R115.

Drop-In Replacement - An alternative refrigerant that can be installed directly into an existing system with minor equipment changes. Most interim alternatives fall into this category.

Ester Oil - A general term that applies to a family of synthetic refrigeration oils based on the chemistry of polyol esters. Ester oils are generally regarded as the oil to use with most of the alternative refrigerants. Ester oils are generally compatible with existing mineral oils, and system components. Ester oils are slightly hygroscopic (likely to absorb moisture from the air) and should be kept in non-porous containers.

Forane® - Arkema (formerly Elf-Atochem) trade name for alternative refrigerants.

Global Warming Potential – (GWP) is a measure of how much a given mass of greenhouse gas is estimated to contribute to global warming. It is a relative scale which compares the gas in question to that of the same mass of carbon dioxide whose GWP is one. Global warming occurs when solar energy penetrates the atmosphere and the resultant infrared energy from the earth's surface is absorbed by certain gases and not allowed to leave. This process is commonly known as the greenhouse effect. Common gases and their GWP: Methane: 21, R-22: 1700, R-32: 650, R-134a: 1300, R-410a: 1890, R-290 (Propane): 3.

HCFC Refrigerant - HCFC refers to the chemical composition of the refrigerant. HydroChloro-Fluoro-Carbon indicates that the refrigerant is comprised of Hydrogen, Chlorine, Fluorine, and Carbon. Common HCFC refrigerants are R-22, R-409a, R-414a, R-414b.

HFC Refrigerant - HFC refers to the chemical composition of the refrigerant. HydroFluoroCarbon indicates that the refrigerant is comprised of Hydrogen, Fluorine, and Carbon. Common HFC refrigerants are R-134a, R-152a.

High Pressure Refrigerants (HP) - A term used for some alternative refrigerants designed to operate in the low temperature (-35° F to 0° F) range. Usually associated with cascade refrigeration systems.

Hygroscopic - A tendency for refrigeration oils to absorb moisture from the atmosphere.

Interim Replacements (SHORT TERM) - Any of a number of refrigerants intended to serve as an intermediate solution during the transition from CFC to HFC refrigerants. Most interim replacements contain HCFC refrigerants like R22.

Klea® - INEOS FLUOR HOLDINGS LIMITED (formerly ICI. Chemicals & Polymers Limited) trade name for alternative refrigerants.

Long Term Replacements - Alternative refrigerants that are considered to have no adverse affect on the stratospheric ozone layer. Most long-term replacements are HFC compounds.

Medium Pressure Refrigerant (MP) - A term used for some alternative refrigerants designed to operate in the medium temperature (0° F to 4° F) range.

Mineral Oil - Refrigeration oil that is currently in use but not compatible with most of the alternative refrigerants. Refrigerant conversions often require. a procedure for the removal of existing mineral oil because of its incompatibility with alternative refrigerants.

Near Azeotrope - A mixture made up of two or more refrigerants with different boiling points that, when in a totally liquid or vapor state, act as one component. However, when changing from vapor to liquid or liquid to vapor, the individual refrigerants -evaporate or condense at different temperatures. Near-azeotropic mixtures have a temperature glide (see below) of less than 10° F and should be charged in the liquid state to assure proper mixture (non-azeotropic) composition.

Ozone Depletion Potential (ODP) - The ODP is the ratio of the impact on ozone of a chemical compared to the impact of a similar mass of CFC-11. CFCs and HCFCs have an ODP ranging from 0.01 to 1.0. As HFCs contain no chlorine their ODP = ZERO. Other common substances have ODPs greater than one: Carbon tetrachloride 1.2 and Halons ranging up to an ODP of 10. .

P.A.G. Oil - A general term that applies to a family of synthetic oils based on the chemistry of Polyalkyline Glycols. The primary application of P.A.G. oils is in automotive air conditioning.

Suva® - E. I. du Pont de Nemours and Company trade name for alternative refrigerants, replaces the Freon® trade name.

Temperature Glide - the temperature difference that occurs between the vapor state and liquid state during evaporation or condensation at constant pressure, i.e. the temperature in the evaporator and condenser is not constant. Temperature glide occurs in near-Zeotropic and Zeotropic mixtures.

Zeotrope - A mixture made up of two or more refrigerants with different boiling points. Zeotropic mixtures are similar to near-azeotropic mixtures with the exception of having a temperature glide greater than 10° F. Zeotropic mixtures should be charged in the liquid state.

Definitions courtesy of National Refrigerants
For more information visit: http://www.refrigerants.com/

19 Using the Heat Gain/Loss Equations

Air conditioning is the process of moving heat from a place where it is not wanted to a place where it doesn't matter. Heating is the addition of sensible and latent energy to the air. When air is conditioned (Heat is added or removed.), the gross total heat removed or added is the sum of the sensible and latent heat commonly referred to as load. Because the operating characteristics of the cooling and heating equipment are affected by sensible and latent loads it is important that they be considered when verifying the operating conditions of the heating or cooling equipment

Gross Total Heat Formula (GTH): This is the total heat added (heated) or removed (cooled) from the air that is being conditioned.

The formula: GTH = 4.5 x CFM x delta-h

Where: GTH = Gross total heat
CFM = Airflow in cubic feet per minute
delta-h = change in enthalpy in Btu per pound of dry air

Total Sensible Heat Formula (TSH): This is the heat added or removed that causes a change in temperature of the air without adding or removing humidity to the air.

The formula: TSH=1.08 x CFM x delta-t

Where: TSH = Total sensible heat
CFM = Airflow in cubic feet per minute
delta-t = Change in temperature across the cooling coil or heat exchanger

Total Latent Heat Formula (TLH): This is heat added or removed that causes a change in state of the air (Humidity added or removed) without changing the temperature of the air.

The formula TLH = 0.68 x CFM x delta -grains

Where: TLH = Total latent heat
CFM = Airflow in cubic feet per minute
delta -grains = Change in grains of moisture in the air

Notes:

20 Derivation of the Air Constants

When using any of the air formulas it is important to understand how to correct for changes in the air density if the air being measured is not standard air. **The air constants apply to standard air at 70° F and 14.7 Pisa, (29.92"hg.)** If air being measured is outside of these parameters, it may require that the constant be recalculated. For most situations the standard air formulas can be used, but if precise measurements are desired, adjustments to the constants should be made. Remember, fans are doing work; they are moving in reality pounds of air. The amount of air they will move in CFM remains constant with a variable mass flow rate, so the cubic feet of air they will move over any given time period will remain the same. The difference is in the density of the air or the number or the pounds per cubic foot. This is important because coil selection software calculates required coil capacities based upon pounds per hour (lb/hr) of air passing through the coil, not CFM.

The constant 4.5 is used to convert CFM to lbs/hr

$$4.5 = \frac{60\ \text{min/hr}}{13.33} \text{ or } (60\text{min} \times 0.075\ \text{lbs/cu ft})$$

Where 13.33 is the specific volume of standard air (cu.ft/lb) and 0.075 is the density (lbs/cu.ft)

If the air being measured is not standard air, the air density will vary with the barometric pressure and the absolute temperature. To recalculate the air density, measure the temperature and obtain the barometric pressure use the following formula:

Air Density (lb/cf) = 1.325 x B_p/T_{abs}

Where: 1.325 (Constant to keep consistent units)
B_p = Barometric Pressure
Tabs = Temperature (Absolute)

Example 1.325 x 29.92/(70°F + 460°F) = 0.0748 ~ 0.075 lb/cu ft
This is how standard air density is calculated

If you were measuring air coming out of a furnace, and the air was 154° F the air density would change as follows

1.325 x 29.92/(154°F + 460°F) = 0.0645

If heated air were used in this formula, the constant would be:
(60min x .0645 lbs/cu ft) = 3.87 instead of 4.5 used for standard air.

The constant used in the sensible heat formula 1.08 is used to convert CFM to lbs/hr and factor in .24 the specific heat of standard air (BTU/lb/°F)

Where: 1.08 = (0.24 x 60)/13.33 or 0.24 x 4.5

$4.5 = \frac{60 \text{ min/hr}}{13.33}$ or (60min x 0.075 lbs/cu ft)

0.24 BTU = specific heat of standard air (BTU/lb/°F)

The constant 0.68 used in the latent heat formula is used to factor out the amount of heat contained in water vapor in BTU/LB

Where 0.68 = (60/13.33) x (1060/7000) or 4.5 x (1060/7000)

Where: 13.33 is the specific volume of standard air (cu.ft/lb)

1060 = average latent heat of water vapor. (Btu/LB)

7000 = grains per lb or water.

$4.5 = \frac{60 \text{ min/hr}}{13.33}$ or (60min x 0.075 lbs/cu ft)

NOTES:

21 FIELD COMMISSIONING TEST FOR AIR CONDITIONERS

Step 1) Verify matched components:

Condenser M/N ____________________
S/N ____________________

Evaporator M/N ____________________
S/N ____________________

Metering Device M/N ____________________ TXV / Fixed (circle)

Air handler/Furnace M/N ____________________
S/N ____________________

Rated capacity of combination from ARI directory ________________ BTUh

Step 2) Set blower to achieve proper airflow (400 CFM/ton AC, 450 CFM/ton ASHP)

Measured CFM actual __________CFM
Selected blower speed __________ (High, Med H, Med L, Low)
TESP __________"WC
Pressure drop across coil __________"WC

Step 3) Charge per manufactures instruction or use superheat calculator for fixed metering device. If TXV and required subcooling is not listed charge to 8° subcooling.

ODA Temp __________°F
Indoor WB __________°F
Required Superheat __________°F
Required Subcooling __________°F

Step 4) Calculate actual BTUh capacity

Return WB ___________°F DB_________°F (or) h__________
Supply WB ___________°F DB_________°F (or) h__________
?h__________

BTUh output = 4.5 x measured CFM x ?h**

BTUh = 4.5 x _____________CFM x ________?h

BTUh = __________________

BTUh = __________________ / Rated BTUh_________________ x 100

Percent of Capacity ___________%

If using Psychrometric program the air density and the enthalpy will be adjusted to the actual air conditions taking into account adjustments in air density due to elevation, and humidity and enthalpy outside of saturation.

Equations, Formulas, and Scientific Principals for Air-conditioning Quick Reference

Heat Gain/Loss Equations

Q = Quantity in BTUh, T = Sensible Temperature, h = Enthalpy
All formulas use standard air constants for dry air : 0.075 lb/cf air density at 70°F and 29.92"Hg

(Quantity Sensible) **Qs = 1.1 x CFM x ?T**

(Quantity Latent) **Ql = 0.68 x CFM x ? grains**

(Quantity Total) **Qt = 4.5 x CFM x ? h**

BTUh output Cooling = 4.5 x CFM (Measured) x ? h

Air Volume/Velocity Formulas

CFM = Cubic feet per minute,
T = Sensible temperature,(°F)
Ta = Temperature absolute (Sensible Temp + 460°F)
Vp = Velocity pressure in "wc,
d = air density in pounds per cubic foot, lb./cu.ft.
Bp = Barometric pressure inches Hg ("Hg)
Q = Known or measured flow (Volumetric Flow Rate) in CFM
Qn = Unknown flow rate in CFM
h = pressure differential inches water column ("WC)
h_n = other flow conditions

CFM = BTUh output/(1.085 x ?T)

Air Velocity Standard Air V = 4005 x v Vp
Air Velocity Non-Standard air V = 1096.7 x v (Vp/d)

Air Density **d = 1.325 x (Bp/Ta)**

To determine flow at a new pressure drop with a known flow and pressure drop

$Qn_{(unknown\ flow)}$ = Q x v (h_n/h)

Determining Volume Flow **Q = AV**
Q = Quantity in CFM
A = Cross sectional area in Ft^2
V = Average Velocity in FPM

Psychrometrics

Measurement (Units)

Airflow = (CFM)
DB = Dry bulb (°F)
WB = Wet bulb (°F)
RH = Relative Humidity (%RH)
W = Humidity Raito (Grains/Lb)
v = Specific Volume (cu.ft/Lb)
h = Enthalpy (Btu/lb)
Dp = Dew point (°F)
vp = Vapor Pressure (in hg)
Grains = Grains of Moisture (Grains)

Total cooling = (tons)
12,000 BTUh = 1 ton

Sensible energy = BTUh
Latent energy = BTUh
+--------------------------
=Total energy = BTUh

Dehumidification = Lbs/hour
7000 grains = 1 pound-$H_2$0

For highly accurate calculations, air density must be considered in calculations. Use of Testo Psychrometric Process Program will perform corrections automatically
www.handsdownsoftware.com

Air Conditioning Charging Rules (410a / R22)

1) Filters and coils must be clean.
2) Airflow must be set correctly (400 CFM/ton A/C 450 CFM ton Hp)
3) Metering device type must be identified. (Fixed or TXV)
4) Charge system using proper method.
   a. Fixed- charge by total superheat method at the condenser using a charging calculator or charging chart.
   b. TXV-charge by subcooling at condenser outlet, (8-10°) and verify superheat at evaporator outlet. (8-12°)

Evaporator Temperature Drop

Temperature drop across the evaporator is a function of the latent and sensible load and will range from 18-24° Measuring temperature drop alone is not a proper way to set airflow.

Note: *Gauges should only be installed when commissioning system for the first time and when the final disposal of the equipment is deemed necessary. Installing gauges during regular service is not required to verify proper operation and is poor service practice. Refer to the Testo Air Conditioning Guide for additional information.*

Fixed metering devices

Superheat must be verified with charging chart or calculator.
High charge = low superheat
Low charge = high superheat

Thermal Expansion Valve

High charge = high subcooling
Low charge = Low subcooling
Normal superheat evaporator outlet 8-12º
Normal subcooling condenser outlet 8-10º

Condenser temperature rise range

25-30° for standard condensers
20-25° for high efficiency condensers
15-20° for ultra high efficiency condensers