CENGAGE

NINTH EDITION

REFRIGERATION & AIR CONDITIONING TECHNOLOGY

Eugene Silberstein • Jason Obrzut
John Tomczyk • Bill Whitman • Bill Johnson

HVAC Excellence

ICC INTERNATIONAL CODE COUNCIL

PAHRA

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***Refrigeration & Air Conditioning Technology* 9E**
Eugene Silberstein, Jason Obrzut, John A. Tomczyk, William M. Johnson, William C. Whitman

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PREFACE

Refrigeration & Air Conditioning Technology is designed and written for students in vocational-technical schools and colleges, community colleges, and apprenticeship programs. The content is in a format appropriate for students who are attending classes full-time while preparing for their first job, for students attending classes part-time while preparing for a career change, or for those working in the field who want to increase their knowledge and skills. Emphasis throughout the text is placed on the practical applications of the knowledge and skills technicians need to be productive in the refrigeration and air-conditioning industry. The contents of this book can be used as a study guide to prepare for the Environmental Protection Agency (EPA) mandatory technician certification examinations. It can be used in the HVACR field or closely related fields by students, technicians, installers, contractor employees, service personnel, and owners of businesses.

This text is also an excellent study guide for the Industry Competency Exam (ICE), the North American Technician Excellence (NATE), the HVAC Excellence, the Refrigeration Service Engineers Society (RSES), the United Association (UA) STAR certification, and the Heating, Air Conditioning, and Refrigeration Distributors International (HARDI) voluntary HVACR technician certification and home-study examinations.

The book is also written to correspond to the National Skill Standards for HVACR technicians. Previous editions of this text are often carried to the job site by technicians and used as a reference for service procedures. "Do-it-yourselfers" will find this text valuable for understanding and maintaining heating and cooling systems.

As general technology has evolved, so has the refrigeration and air-conditioning industry. A greater emphasis is placed on digital electronic controls and system efficiency.

Global warming has become a major environmental issue. When HVACR systems are working correctly and efficiently, they will greatly reduce energy consumption and greenhouse gases. Organizations like the Green Mechanical Council (GreenMech) are advocates for the HVACR industry and assist the industry in meeting with government, educational, industry, and labor interests to find solutions to the world's global-warming problem. GreenMech has created a scoring system designed to help engineers, contractors, and consumers know the "green value" of each mechanical installation. The "green value" encompasses the system's energy efficiency, pollution output, and sustainability. Realtors, building inspectors, builders, and planning and zoning officials will now have some knowledge about and guidance on how buildings and mechanical systems are performing. Green buildings and green mechanical systems are becoming increasingly popular in today's world as a way to curb global warming.

Energy audits have become an integral part of evaluating and assessing an existing building's energy performance. Higher efficiency standards for the energy performance of new buildings have been established. Higher levels of training and certification have been developed for HVACR technicians to meet the needs of more sophisticated, energy-efficient buildings and HVACR equipment.

TEXT DEVELOPMENT

This text was developed to provide the technical information necessary for a technician to be able to perform satisfactorily on the job. It is written at a level that students can easily understand. Practical application of the technology is emphasized. Terms commonly used by technicians and mechanics have been used throughout to make the text easy to read and to present the material in a practical way. Many of these key terms are also defined in the glossary. This text is updated regularly in response to market needs and emerging trends. Refrigeration and air-conditioning instructors have reviewed each unit.

Illustrations and photos have been updated and are used extensively throughout the text. Full-color treatment of photos and illustrations helps amplify the concepts presented.

No prerequisites are required for this text. It is designed to be used by beginning students, as well as by those with training and experience.

ORGANIZATION

Considerable thought and study have been devoted to the organization of this text.

The text is organized so that after completing the first four sections, students may concentrate on courses in refrigeration or air-conditioning (heating and/or cooling). If the objective is to complete a whole program, the instruction may proceed until the sequence scheduled by the school's curriculum is completed.

NEW TO THIS EDITION

The 9th edition includes more than 400 new and revised figures and images. Many of these images have been recolored to improve accessibility for learners with different forms of color-blindness.

Learning objectives have been validated and carefully mapped to content in all units. Each unit's objectives clearly align to the major topics in the unit and to the unit's review questions. This alignment is detailed for instructors in the form of a Content Map, which is now available in the instructor resource center.

Unit summaries have been updated and moved from the core reading to the instructor resource center. This placement encourages students to use the summaries as a study supplement rather than a main source of information and gives instructors full control over whether and when their students will have access to this resource.

SEVERAL SAFETY TOPICS HAVE BEEN UPDATED OR EXPANDED, INCLUDING:

- safe workplace surroundings
- working in confined spaces
- personal protection equipment (PPE)
- first aid
- ladder safety
- fire extinguisher usage
- heat-related injuries

THE FOLLOWING TECHNICAL TOPICS HAVE BEEN ADDED, UPDATED, OR EXPANDED:

New Coverage	Updated Coverage	Expanded Coverage
• System evacuation without the use of a gauge manifold • General refrigeration • Retrofitting considerations and guidelines • Combustion air • Compressor testing • Chilled beam technology	• Leak repair requirements and EPA regulations • Capacitor testing • Fan-cycling devices • Scroll compressor efficiency • Piston metering devices • Combustion and high-efficiency furnaces • Temperature difference (TD)	• Refrigerant numbering system • Azeotropic and near-azeotropic blends • Specific volume, specific gravity, and density • R-value, U-value, and calculations • Systems with combinations of metering devices • Indoor fan motor control

NEW TO THIS EDITION'S MINDTAP:

In addition to all the updates included in the printed text, the 9th edition MindTap adds the following enhancements:

- Each unit in the MindTap now includes an introductory video by author Eugene Silberstein to explain how the unit's content will support the learner's HVACR career.
- Review Questions are now auto-graded, providing immediate feedback and full explanations for learners.
- The Electricity and HVACR Troubleshooting simulations have been updated to version 4.0, with improved loading times and smoother LMS integration, enhanced user tutorials, new start screens in troubleshooting scenarios, shareable badges, and more.

HOW TO USE THIS TEXT AND SUPPLEMENTARY MATERIALS

This text may be used as a classroom text, as a learning resource for an individual student, as a reference text for technicians on the job, or as a homeowner's guide. An instructor may want to present the unit objectives, briefly discuss the topics included, and assign the unit to be read. The instructor then may want to discuss the material with students. This can be followed by students completing the review questions, which can later be reviewed in class.

The instructor resource DVD may be used to access a computerized test bank for end-of-unit review questions, teaching tips, PowerPoint® presentations, and more.

FEATURES OF THE TEXT

Objectives

Objectives are listed at the beginning of each unit. The objective statements have been stated clearly and simply to give students direction.

OBJECTIVES

After studying this unit, you should be able to

- discuss applications for high-, medium-, and low-temperature refrigeration.
- describe the term *ton of refrigeration*.
- describe the basic refrigeration cycle.
- explain the relationship between pressure and the boiling point of water or other liquids.
- describe the function of the evaporator or cooling coil.
- explain the concept of superheat as it applies to the evaporator.
- explain the purpose of the compressor.
- list three types of compressors normally used in residential and light commercial buildings.
- discuss the function of the condenser.
- explain the concept of subcooling as it applies to the condenser.
- state the purpose of the metering device.
- list four characteristics to consider when choosing a refrigerant for a system.
- list the designated cylinder colors for three commonly used refrigerants.
- discuss four commonly used refrigerants and their applications.
- describe how refrigerants can be stored or processed while refrigeration systems are being serviced.
- plot a refrigeration cycle for refrigerants (R-22 and R-134a) on a pressure/enthalpy diagram.
- plot a refrigeration cycle on a pressure/enthalpy diagram for refrigerant blends R-404A and R-410A.
- plot a refrigeration cycle on a pressure/enthalpy diagram for a refrigerant blend (R-407C) that has a noticeable temperature glide.

Safety Checklists

A Safety Checklist is presented at the beginning of each unit, when applicable, immediately following the Objectives. This checklist emphasizes the importance of safety and is included in units where "hands-on" activities are discussed.

Safety is emphasized throughout the text. In addition to the Safety Checklist at the beginning of most units, safety precautions and techniques are highlighted throughout. It would be impossible to include a safety precaution for every conceivable circumstance that may arise, but an attempt has been made to be as thorough as possible. The overall message is to work safely whether in a school shop, laboratory, or on the job and to use common sense.

SAFETYCHECKLIST

Areas in which there is the potential for refrigerant leaks should be properly ventilated.
Extra precautions should be taken to ensure that no refrigerant leaks occur near an open flame.
Refrigerants are stored in pressurized containers and should be handled with care.
Eye protection and gloves should be worn when checking system pressures or when otherwise working on air-conditioning and refrigeration systems.
Only transfer refrigerants from a system into DOT-approved containers.

Recovery/Recycling/Reclaiming/Retrofitting

Discussions relating to recovery, recycling, reclaiming, retrofitting, or other environmental issues are highlighted in blue throughout the text. In addition, one complete unit on refrigerant management is included—Unit 9, "Refrigerant and Oil Chemistry and Management—Recovery, Recycling, Reclaiming, and Retrofitting."

valves. However, when the system utilizes only circulators, flow control valves are desirable. Some circulator manufacturers are now installing flow control valves right on the circulators themselves to ease the installation process, **Figure 33.50**.

Figure 33.49 A flow control valve. Courtesy Bell and Gossett

ting of 1.0 will cause the boiler to maintain a water temperature of 160°F if the outside ambient temperature is 20°F. The same control setting will cause the boiler water temperature to drop to 140°F if the outside ambient temperature rises to 40°F. 4R *As of September 2012, all newly installed boilers are required to have some type of reset control strategy to automatically adjust the boiler water temperature.* 4R

Green Awareness

As previously mentioned, global warming stemming from the uncontrolled rate of greenhouse gas emissions is a major global environmental issue. Buildings are important users of energy and materials and so are a major source of the greenhouse gases that are the by-products of energy and materials use. At the time of this writing, there are approximately 5 million commercial buildings and 125 million housing units in the United States. Surprisingly, almost every one of their mechanical systems is obsolete. Discussions relating to the green awareness movement (e.g., lowering energy costs, reducing operating and maintenance costs, increasing productivity, and decreasing the amount of pollution generated) are highlighted in green throughout the text.

good pump performance. The vacuum pump oil should be clean and clear; if it is cloudy, moisture is likely to be present. The pump should then be serviced by changing the oil. **NOTE:** *For the best performance, only approved vacuum pump oil should be used. Any other oil will have a vapor pressure that is too high and thus prevent the achievement of deep vacuums.* *Be sure to dispose of the old oil in an environmentally appropriate manner.*

With the new oil in the pump, run the pump long enough to get up to operating temperature; it will usually be too hot to touch or hold. Drain the oil again. With fresh oil in

HVACR GOLDEN RULES

When making a service call to a business:

- Never park your truck or van in a space reserved for customers.
- Look professional and be professional.
- Before starting troubleshooting procedures, get all the information you can regarding the problem.
- Be extremely careful not to scratch tile floors or to soil carpeting with your tools or by moving equipment.
- Be sure to practice good sanitary and hygiene habits when working in a food preparation area.
- Keep your tools and equipment out of the customers' and employees' way if the equipment you are servicing is located in a normal traffic area.
- Be prepared with the correct tools and ensure that they are in good condition.
- Always clean up after you have finished. Try to provide a little extra service by cleaning filters, oiling motors, or providing some other service that will impress the customer.
- Always discuss the results of your service call with the owner or representative of the company. Try to persuade the owner to call if there are any questions as a result of the service call.

HVACR Golden Rules

Golden Rules for the refrigeration and air-conditioning technician give advice and practical hints for developing good customer relations. These "golden rules" appear in appropriate units.

rate to the unit as per the manufacturer's required specifications.

Hardness: The amount of calcium and magnesium measured in grains per gallon. See the following standards chart from the U.S. Bureau of Standards:

Water Hardness

Description	Grains per Gallon	Parts per Million (Total Dissolved Solids)
Soft Water	Less than 1.0	Less than 17.1
Slightly Hard	1.0 to 3.5	17.1 to 60.0
Moderately Hard	3.5 to 7.0	60.0 to 120.0
Hard Water	7.0 to 10.5	120.0 to 180.0
Very Hard	10.5 and over	180.0 and over

Note: 7000 grains = 1 pound.

Iron: A compound or bacteria found generally in well water. Iron compounds cause a rust-colored scale. Iron bacteria show up as rust-colored slime.

pH: The term used to express the level of acidity or alkalinity in water or solutions. The scale for pH ranges

Turbidity: The degree of water cloudiness generally caused by high mineral saturation or the presence of air bubbles in the water.

Water softener: A device that uses salt to provide an ion exchange that reduces the hardness of water, making it less likely to produce scale.

One last term that is usually understood by the service technician but seldom considered by the customer is **preventive maintenance.** *This refers to the regularly scheduled maintenance performed on a unit, including inspecting, cleaning, sanitizing, and servicing of the ice machine and external water filtration/treatment system. Preventive maintenance pays big benefits. Every equipment manufacturer provides recommendations and instructions that detail the steps necessary to perform preventive maintenance. This process, along with providing proper water filtration and treatment at the time of initial installation, is vital for protecting the customer's investment and maintaining maximum efficiency—as well as ensuring a longer life for the ice machine.* A basic understanding of these terms will help a service technician communicate any water-quality concerns to a filter manufacturer and to the customer. This will definitely help in resolving ice machine water-quality issues.

Preventive Maintenance

Preventive Maintenance procedures are included in many units and relate specifically to the equipment presented in that unit. Technicians can provide some routine preventive maintenance service when on other types of service calls as well as when on strictly maintenance calls. The preventive maintenance procedures provide valuable information for the new or aspiring technician and homeowner, as well as for those technicians with experience.

Problem	Possible Cause	Possible Repair
No cooling, outdoor unit not running, indoor fan running	Open outdoor disconnect switch Open fuse or breaker Faulty wiring	Close disconnect switch. Replace fuse, reset breaker, and determine problem. Repair or replace faulty wiring or connections.
No cooling; indoor fan and outdoor unit will not run	Low-voltage control problem A. Thermostat B. Interconnecting wiring or connections C. Transformer	Repair loose connections or replace thermostat and/or subbase. Repair or replace wiring or connections. Replace if defective. **SAFETY PRECAUTION:** *Look out for too much current draw due to a ground circuit or shorted coil.*

Diagnostic Charts

Diagnostic Charts are included at the end of many units. These charts include material on troubleshooting and diagnosis.

SERVICE CALL 1

A customer calls indicating that the boiler in the equipment room at a motel has hot water running out and down the drain all the time. Another service company has been performing service at the motel for the last few months. *The problem is that the water-regulating valve (boiler water feed) is out of adjustment. Water is seeping from the boiler's pressure relief valve,* **Figure 14.65**.

The technician arrives at the motel, parking alongside the building so as not to block the front door or the motel's

Service Technician Calls

In many units, practical examples of service technician calls are presented in a down-to-earth situational format. These are realistic service situations in which technicians may find themselves. In many instances, the solution is provided in the text, and in others the reader must decide what the best solution should be. These solutions are provided in the Instructor's Manual. The Service Technician Calls will now incorporate customer relations and technician soft skills.

REVIEW QUESTIONS

1. The control voltage that is typically used in split-type residential central air-conditioning systems is
   A. 24 V.
   B. 48 V.
   C. 96 V.
   D. 115 V.
2. What device is used to produce the control voltage that is used to power the control circuits of a split-type residential central air-conditioning system?
   A. Step-down transformer
   B. Step-up transformer
   C. Low-voltage thermostat
   D. Line-voltage thermostat
3. All of the following are true statements regarding line-voltage thermostats and control wiring except
   A. An electrician's license is often required to run line-voltage control wiring.
   B. Line-voltage thermostats and controls respond faster than low-voltage thermostats.
   C. Line-voltage thermostats and controls are not as sensitive as low-voltage thermostats.
   D. Line-voltage thermostats must be matched to the voltage and current of the circuit.
4. System lag is the result of which of the following with regards to a heating system?
   A. The residual system heat increasing the space temperature
   B. The amount of heat generated in the thermostat
7. Which of the following is likely to be found on a line-voltage thermostat?
   A. Contacts with low amperage ratings
   B. 18-gauge or 22-gauge wire connections
   C. Lightweight switches and buttons
   D. Locking or otherwise secure cover
8. If a heated space reaches a maximum temperature of 78°F and a minimum temperature of 71°F, the difference between these two temperatures is referred to as the
   A. temperature lag.
   B. system lag.
   C. system overshoot.
   D. temperature swing.
9. Why is measuring the temperature of a solid object challenging for the HVACR technician?
   A. The temperature of solid objects is not uniform throughout.
   B. The entire thermometer probe must be at the temperature of the solid.
   C. Thermometers are not designed to measure the temperature of solids.
   D. Solid objects do not transfer heat as effectively as other forms of matter.
10. What method is most likely to be used to measure the temperature of a liquid contained in an open vessel?
   A. Immersion

Review Questions

Review Questions follow the Summary in each unit and can help to measure the student's knowledge of the unit. There are a variety of question types—multiple choice, true/false, short answer, short essay, and fill-in-the-blank.

SUPPORT MATERIALS

LAB MANUAL

The Complete HVAC Lab Manual was developed out of the need for a lab manual that comprehensively covers the knowledge and skills that are required for an HVACR technician entering the industry. It was designed to support the hands-on application and practice required within the HVACR program.

INSTRUCTOR RESOURCES

- Syllabus. This is the standard course syllabus for this textbook, providing a summary outline for teaching HVACR.
- Teaching Tips. Teaching hints form a basis for presenting concepts and material. Key points and concepts can be highlighted graphically to enhance student retention.
- PowerPoint Presentation. These slides can be used to outline a lecture on the concepts and material. Key points and concepts are highlighted graphically to enhance student retention.
- Image Gallery. This database of key images (all in full color) taken from the text can be used in lecture presentations, as transparencies, for tests and quizzes, and with PowerPoint presentations.
- Test Bank. Over 1000 questions of varying levels of difficulty are provided in multiple-choice and short-answer formats for assessing student comprehension. This versatile tool allows the instructor to manipulate the data to create original tests.

VIDEO DVD SET

A seven-DVD video set addressing over 120 topics covered in the text is available. Each DVD contains four 20-minute videos. To order the seven-DVD set, reference ISBN: 978-1-111-64451-2.

MINDTAP

MindTap is well beyond an eBook, a homework solution or digital supplement, a resource center website, a course delivery platform, or a Learning Management System. MindTap is a new personal learning experience that combines all your digital assets—readings, multimedia, activities, and assessments—into a singular learning path to improve student outcomes.

INSTRUCTOR SITE

An Instructor Companion website containing supplementary material is available. This site contains an Instructor's Manual, teaching tips, syllabus, lecture outline, an image gallery of text figures, unit presentations done in PowerPoint, and testing powered by Cognero.

Cengage Learning Testing Powered by Cognero is a flexible, online system that allows you to:

- author, edit, and manage test bank content from multiple Cengage solutions
- create multiple test versions in an instant
- deliver tests from your LMS, your classroom, or wherever you want

Contact Cengage or your local sales representative to obtain an instructor account.
To access an Instructor Companion website from SSO Front Door:

1. Go to http://login.cengage.com and log in using the instructor e-mail address and password.
2. Enter author, title, or ISBN in the **Add a title to your bookshelf** search.
3. Click **Add to my bookshelf** to add instructor resources.
4. At the Product page, click the **Instructor Companion site** link.

DELMAR ONLINE TRAINING SIMULATION: HVAC 4.0

Delmar Online Training Simulation: HVAC is a 3D immersive simulation that offers a rich learning experience and mimics field performance. To address the critical area of Electricity, it offers a learning path from basic electrical concepts to real-world electrical troubleshooting. This innovative product includes dynamic interactive wiring diagrams in two modes: an open sandbox mode for exploration and experimentation, and a tutorial mode where the proper sequencing required for sound electrical practice is provided. Both modes are supported by an adaptive question engine. Learning electrical theory, and trying and testing sound electrical practice prepares the student for life-like, simulated exposure to faults with the HVACR equipment that follows. It also challenges learners to master diagnostic and troubleshooting skills across seven pieces of HVACR equipment found in the industry—Gas Furnace, Oil Furnace, Gas Boiler, Split Residential A/C, Commercial A/C, Heat Pumps, and Commercial Walk-in Freezers. Soft skills are also included within the simulation.

To create successful learning outcomes, Delmar Online Training Simulation: HVACR offers approximately 200 scenarios which allow students to troubleshoot and build diagnostic and critical thinking skills. Two modes within the simulation promote incremental learning: Training Mode and Challenge Mode. Training Mode has fixed scenarios to aid in familiarizing the user with the equipment, the problem needing attention, and the capabilities of the simulation. Challenge Mode has randomized scenarios within three levels: Beginner, Intermediate, and Advanced. Both modes require learners to diagnose a fault or faults and perform the repair successfully while materials and labor costs are tracked. An integrated digital badging system helps students track their progress and adds additional engagement and motivation. Simulation-based videos teach students key troubleshooting concepts as well as familiarize them with the simulation. The instructional design allows for full open engagement, so students do not have artificial guardrails leading them to a conclusion.

Combining sound instructional design with top-quality computer immersive technology, learners develop critical thinking skills and apply them to real-world customer service calls in a simulated, 3D, life-like setting. This performance simulation complements live training practice by reinforcing good habits, and even presenting scenarios that are impractical (dangerous, expensive, etc.) to create in labs or in a residence. Available for instant purchase on www.cengagebrain.com.

ABOUT THE AUTHORS

EUGENE SILBERSTEIN

Since entering the HVACR industry in 1980, Eugene has taken on many roles ranging from field technician and system designer to company owner, teacher, administrator, consultant, and author. Eugene is presently the Director of Technical Education and Standards at the ESCO Institute.

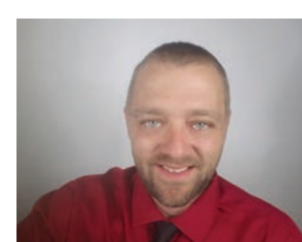
Eugene has 25 years of teaching experience and has taught air-conditioning and refrigeration at many institutions including high school vocational programs, proprietary post-secondary institutions, and community colleges. In December of 2015, Eugene retired from his tenured teaching position at Suffolk County Community College, in Brentwood, New York, to join the ESCO Group and relocate to Southern California.

Eugene earned his dual bachelor's degree from The City College of New York (New York, NY) and his master's of science degree from Stony Brook University, (Stony Brook, NY) where he specialized in Energy and Environmental Systems, studying renewable and sustainable energy sources such as wind, solar, geothermal, biomass, and hydropower. He earned his Certified Master HVACR Educator (CMHE) credential from HVAC Excellence and the ESCO Group in 2010. Eugene also carries ASHRAE's BEAP credential, which classifies Eugene as a Building Energy Assessment Professional. He is also an active member of many industry societies.

Eugene served as the subject matter expert on over 15 HVACR-related educational projects. His most notable work is Cengage Learning's *Refrigeration and Air Conditioning Technology title*, which is presently in its 9th Edition (2021). This book is used in over 1000 schools both in this country and abroad to help individuals learn, and master, the skills required to service, install, design, service, and troubleshoot HVACR equipment. Other book credits include *The Complete HVAC Lab Manual (2019), Refrigeration and Air Conditioning Technology, 6th and 7th Editions (2008, 2012), Residential Construction Academy: HVAC, 1st and 2nd Editions (2005, 2012), Pressure Enthalpy Without Tears (2006), Heat Pumps, 1st and 2nd Editions (2003, 2016),* and *Psychrometrics Without Tears* (2014). In addition to his book credits, Eugene has written the production scripts for over 30 HVACR educational videos and has written articles for the industry's newspapers, magazines, and other periodicals.

Eugene was selected as one of the top three HVACR instructors in the country for the 2005/2006, 2006/2007, and 2007/2008 academic school years by the Air-Conditioning, Heating and Refrigeration Institute (AHRI) and the Air Conditioning, Heating and Refrigeration (ACHR) News.

JASON OBRZUT



In 2002, Jason Obrzut graduated from the HVAC Technical Institute in Chicago, kick-starting his impressive career in the HVACR industry. Upon graduating from school, Jason began working as a service technician and, within a short time, became an installation supervisor, and ultimately a business owner. While working during the day, he returned to the HVAC Technical Institute as a part-time, evening instructor. Teaching quickly became his passion and working in the field took the proverbial backseat as his part-time night teaching assignment morphed into a full-time teaching position. While teaching, Jason developed, wrote, and implemented the curriculum that is currently being taught at the school. His dedication to his students and the institution became evident and, after a few short years, he assumed the role as the school's Director of Education in addition to being the center's lead HVACR instructor.

In 2016, The ACHR News recognized Jason as one of the "Top 40 Under 40" in the HVACR industry. He is affiliated with numerous HVACR industry organizations including Refrigeration Service Engineers Society (RSES), the ESCO Group, and HVAC Excellence. At HVAC Excellence's 2016 National HVAC Educators and Trainers Conference (NHETC), Jason participated in the first annual Teachers-N-Trainers (TnT) competition and took 1st place in a field of over 60 participants. Jason is one of only 125 instructors nationwide who has had the title of Certified Master HVAC/R Educator (CMHE) bestowed upon him. In addition, he possesses other industry certifications, such as Certified Subject Matter Educator (CSME) certificates from the ESCO Group. Jason has recently accepted a full-time position with the ESCO Institute, an industry partner of Cengage Learning, where he will be taking on a role as part of the content development team to help improve the quality of HVACR education and training.

JOHN TOMCZYK

John Tomczyk received his associate's degree in refrigeration, heating, and air-conditioning technology from Ferris State University in Big Rapids, Michigan; his bachelor's degree in mechanical engineering from Michigan State University in East Lansing, Michigan; and his master's degree in education from Ferris State University. Mr. Tomczyk has worked in refrigeration, heating, and air-conditioning service and technical writing consultation for both the academic and industrial fields for numerous years—enabling him to bring a wealth of experience to this text. His technical articles have been featured in many HVACR magazines and journals. Mr. Tomczyk is also the author of *Troubleshooting and Servicing Modern Air Conditioning and Refrigeration Systems.* Mr. Tomczyk has 29 years of teaching experience at the Refrigeration, Heating, and Air-Conditioning Technology program at Ferris State University and is a member of many HVACR trade organizations.

BILL JOHNSON

Now retired, Bill Johnson has taught heating, air-conditioning, and refrigeration for more than two decades in various technical colleges and factory schools. A graduate of Southern Technical Institute, a branch of Georgia Tech in Atlanta, Georgia, he has also served as Service Manager for a major manufacturer for six years. Mr. Johnson owned his own HVACR business for 10 years and has been a member of the Refrigeration Service Engineers Society and the American Society of Heating Refrigerating Air Conditioning Engineers. His authoring credits include three major textbooks on the market today as well as their ancillary materials. He also writes a monthly article—BTU Buddy—that is available online.

BILL WHITMAN

Bill Whitman (July 1, 1930–August 12, 2018)
Bill Whitman, along with co-author Bill Johnson, spent 5 years collaborating on the first edition of *Refrigeration and Air Conditioning Technology*, which published in 1986. Little did they know that the title would grow in popularity, be used in nearly 1000 career and technical education programs across the country, and would be the huge success that it is, even 30-plus years after its initial release.

Bill was a native of Bennington, Vermont and a veteran of the Korean War while in the Air Force. He graduated from Keene State College in Keene, New Hampshire with a degree in industrial education and went on to achieve a master's degree in school administration at St. Michael's College in Winooski, Vermont.

After instructing drafting classes for 3 years, Bill became the Director of Vocational Education for the Burlington Public School System, Burlington, Vermont, a position he held for 8 years. He spent 5 years as the Associate Director of Trident Technical College in Charleston, SC. Later, Bill accepted a position as head of the Department of Industry at Central Piedmont Community College, Charlotte, NC where he supervised the operation of six technical programs.

Bill was a soft spoken, easy going person that was easy to work with. His hobbies have been sailing, golf, and pool, all of which he was an expert at. He is missed by all who had the pleasure of meeting him.

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PARTNERSHIP FOR AIR-CONDITIONING, HEATING, REFRIGERATION ACCREDITATION (PAHRA)

The Partnership for Air-Conditioning, Heating, Refrigeration Accreditation (PAHRA) is a partnership between HVACR educators and the HVACR industry that recognizes programs that have met or exceeded industry-validated standards.

- The purpose of PAHRA is to improve the quality of training offered at all levels of education by meeting or exceeding established industry standards in the heating, ventilation, air conditioning and refrigeration (HVACR) industry.
- The development of the evaluation standards for educational programs in HVACR is the work of all the parties interested in the HVACR Industry and the educational future of the industry's technicians.
- The PAHRA program was developed, supported, and implemented by a number of HVACR educators, administrators and vocational technical education state supervisors.

www.pahrahvacr.org

HVAC EXCELLENCE

HVAC Excellence was established in 1994 to improve the technical competency of the HVACR industry through validation of the technical education process. By creating industry-embraced standards for education, and verifying that they have been met, HVAC training programs are able to meet the challenges facing our industry by continuous improvement in the way that technicians are prepared to enter the workforce. One way that HVAC Excellence ensures that students receive high quality training is through programmatic accreditation.

Programmatic accreditation is an independent, non-governmental, third-party review of an educational program. Programmatic accreditation of HVACR educational programs readily identifies HVACR educational programs that possess the resources, and administrative support, to prepare students for entry-level positions in the HVACR industry.

Accreditation standards require a thorough examination of: mission of program, administrational responsibilities, finances and funds, student services, instruction design and program elements, physical facilities, equipment and tools, cooperative training and instructor qualifications. HVAC Excellence is the industry's oldest and largest provider of HVACR programmatic accreditation.

In addition to accrediting HAVCR training programs, HVAC Excellence and its affiliates offer entry-level technician certifications, advanced-level service technician certifications and instructor credentials. With their portable and stackable credentials, HVAC Excellence follows individuals through their entire HVACR careers.

The authors of this text have taken the initiative to ensure that the 9th Edition of Refrigeration and Air Conditioning Technology has been cross-walked to HVAC Excellence's task and competency list. This cross-walk ensures that this text can be used to help students prepare for the nationally-recognized certification examinations that they will take prior to entering the field.

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SECTION 1

THEORY OF HEAT

INTRODUCTION

Refrigeration is a complex topic that covers a wide range of areas. Refrigeration relates to the cooling of substances to

- preserve and transport food products,
- produce ice,
- aid in the manufacturing of many commercial products, and
- aid in medical research.

In addition, refrigeration plays vital roles in many other industrial, commercial, and residential applications. Air-conditioning, a form of refrigeration, refers to space heating, cooling, dehumidifying, humidifying, air filtering, exhausting, ventilating, and improving overall indoor air quality for those in the occupied space. Very often, the term air-conditioning is associated only with cooling processes but, as you can see, it involves much more than that.

HISTORY OF REFRIGERATION AND AIR-CONDITIONING (COOLING)

Most evidence indicates that the Chinese, as early as 1000 B.C., were the first to store ice and snow in order to cool wine and other food products. Early Greeks and Romans used underground pits, which were insulated with straw and weeds, to store ice for long periods of time. The ancient people of Egypt and India cooled liquids in porous earthen jars. These jars were set out in the dry night air, and the evaporation of the liquids seeping through the porous walls provided the cooling. Some evidence indicates that ice was even produced from the vaporization of water through the walls of these jars.

In the eighteenth and nineteenth centuries, natural ice was cut from lakes and ponds in the winter in the northern United States and stored underground for use in the warmer months. Some of this ice was packed in sawdust and transported to southern states to be used for preserving food. In the early twentieth century, it was still common in the northern states for ice to be cut from ponds and then stored in open ice houses. Sawdust insulated the ice, which was then delivered to homes and businesses.

In 1823, Michael Faraday discovered that certain gases under constant pressure will condense when they cool. In 1834, Jacob Perkins, an American, developed a closed refrigeration system using liquid expansion and then compression to produce cooling. He used ether as a refrigerant, a hand-operated compressor, a water-cooled condenser, and an evaporator in a liquid cooler. He was awarded a British patent for this system. In Great Britain during the same year, L. W. Wright produced ice by the expansion of compressed air.

TIME LINE

1800

1823

Michael Faraday discovered that certain gases under constant pressure will condense when they cool.

1834

L. W. Wright produced ice by expansion of compressed air. Jacob Perkins developed a closed refrigeration system using expansion of a liquid and compression to produce cooling. David Perkins developed a closed refrigeration system using the expansion and compression of ether.

1842

John Gorrie used dripping ammonia to produce cooling.

1850

1858

Ferdinand Carré developed an ammonia mechanical refrigerator. It made blocks of ice.

1875

Raoul Pictet used sulfur dioxide as a refrigerant.

1881

Gustavus Swift was developing refrigeration railcars.

1890

Michael Cudahy improved railcar refrigeration.

In 1842, Florida physician John Gorrie placed a vessel of ammonia atop a stepladder and let the ammonia drip, which then vaporized and produced a cooling effect. This basic principle is still used in air-conditioning and refrigeration today. In 1856, Australian inventor James Harrison, an immigrant to America from Scotland, also used ammonia experimentally, but reverted to an ether compressor in equipment that had been previously constructed. In 1858, a French inventor, Ferdinand Carré, developed a mechanical refrigerator using liquid ammonia in a compression machine that produced blocks of ice. Generally, mechanical refrigeration was first designed to produce ice.

In 1875, Raoul Pictet of Switzerland first used sulfur dioxide as a refrigerant. Sulfur dioxide was not only a good refrigerant, but also served as a good lubricant for the system's compressor. This refrigerant was used frequently after 1890 and on British ships into the 1940s. Refrigeration railcars were developed by Gustavus Swift in 1881, and in 1890, Michael Cudahy had improved their design. Sulfur dioxide was also used in the Audiffren-Singrün refrigeration machine patented in 1894 by a French priest and physicist, Father Marcel Audiffren. It was originally designed to cool liquids, such as wine, for the monks.

In 1902, Willis Carrier, the "father of air-conditioning," designed a humidity control to accompany a new air-cooling system. He pioneered modern air-conditioning. In 1915, he, along with other engineers, founded Carrier Engineering, now known as the Carrier Corporation.

In 1918, the Kelvinator company, originally named the Electro Automatic Refrigeration Corporation, came into being and sold the first Kelvinator household units. The refrigerator was a remote-split type in which the condensing unit was installed in the basement and connected to an evaporator in a converted icebox in the kitchen. The Guardian Refrigerator Company developed a refrigerator they called "the Guardian." General Motors purchased Guardian in 1919 and developed the refrigerator they named Frigidaire. By 1929, refrigerator sales topped 800,000. The average price fell from $600 in 1920 to $169 in 1939. By the 1930s, refrigeration was well on its way to being used extensively in American homes and commercial establishments.

In 1923, Nizer introduced a water-cooled compressor and condensing unit for ice cream cabinets, considered to be the first commercial ice cream unit. Nizer soon merged into the Kelvinator Company. Between 1923 and 1926, units produced by Savage Arms were among the first automatically controlled commercial units. The Savage Arms compressor had no seals, no pistons, and no internal moving parts. A mercury column compressed the refrigerant gas as the entire unit rotated. The compressor was practically noiseless.

In 1928, Paul Crosley introduced an absorption-type refrigeration machine so that people could have refrigeration in rural areas where electricity was scarce. These systems, which used a mixture of ammonia and water, could lower the inside temperature to 43°F or less. Ice cubes actually could be made for a period of about 36 hours, depending on the room temperature. These machines would need periodic "recharging" by heating the system over a kerosene burner.

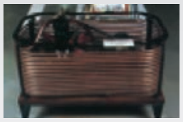
In 1939, the Copeland Company introduced the first successful semihermetic (Copelametic) field-serviceable

1894 The Audiffren-Singrün refrigerating machine used a hermetically sealed system.

1900

1902 Willis Carrier designed humidity control for a new air-cooling system and pioneered modern air-conditioning. Willis Carrier also originated the Carrier equation upon which the psychrometric chart and all air-conditioning is based.

1918 Kelvinator refrigeration unit introduced.



1919 FRIGIDAIRE

Guardian Refrigerator Company developed a refrigerator they called the Guardian. General Motors purchased Guardian in 1918 and the name was changed to Frigidaire.

1923 Nizer water-cooled compressor and condenser for ice cream cabinets. Nizer made the first ice cream unit for the market. Nizer soon merged into Kelvinator.

1926 Savage Arms ice cream unit introduced. It contained a unique mercury column compressor with no seals, pistons, or lubrication.

1928 Crosley Icy Ball—An absorption-type refrigerator machine provided refrigeration in rural areas without electricity.

compressor. Three engineering changes made these compressors successful:

1. Cloth-insulated motor windings were replaced with Glyptal insulation.
2. Neoprene insulation replaced porcelain enamel in the electric terminals.
3. Valves were redesigned to improve efficiency.

Many different refrigerants have been developed over the years. R-12, a chlorofluorocarbon (CFC), was developed in 1931 by Thomas Midgley of Ethyl Corporation and C. F. Kettering of General Motors. It was produced by DuPont. In 1974, two professors from the University of California, Sherwood Rowland and Mario Molina, presented the "ozone theory." Their hypothesis was that CFC refrigerants released into the atmosphere were depleting the earth's protective ozone layer. Scientists conducted high-altitude studies and concluded that CFCs were indeed linked to ozone depletion. Representatives from the United States, Canada, and more than 30 other countries met in Montreal, Canada, in September, 1987, to try to solve the problem of released refrigerants and the effect they had on ozone depletion. This meeting produced the Montreal Protocol, which by 1989 had been ratified by 100 nations. It mandated a global freeze on the production of CFCs at 1986 levels. The Protocol also froze production of hydrochlorofluorocarbon (HCFC) refrigerants at their 1986 levels, beginning in 1992. In addition, the Protocol set a schedule of taxes on CFC refrigerants. As research on ozone depletion continues today, reassessments and updates to the Montreal Protocol also continue. At the time of this writing, the most current updates are as follows:

- 1990 (November)—President George H. W. Bush signed the Clean Air Act amendments that initiated production freezes and bans on certain refrigerants.
- 1992 (July)—The EPA made it against the law to intentionally vent CFC and HCFC refrigerants into the atmosphere.
- 1993—The EPA mandated the recycling of CFC and HCFC refrigerants.
- 1994 (November)—The EPA mandated a technician certification program deadline. Current HVACR technicians had to be EPA-certified by this date.
- 1995 (November)—The EPA made it against the law to intentionally vent alternative refrigerants (HFCs and all refrigerant blends) into the atmosphere.
- 1996—The EPA made it illegal to manufacture or import CFC refrigerants.
- 1996—The EPA put into place a gradual HCFC production phaseout schedule, which will totally phase out the production of HCFC refrigerants by the year 2030.
- 1998 (June)—The EPA proposed new regulations on recovery/recycling standards, equipment leak rates, and alternative refrigerants.

TIME LINE

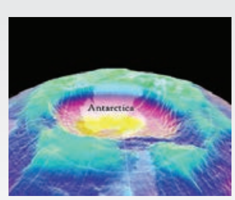
1929
Household refrigerator sales topped 800,000.

1931
Refrigerant R-12 was developed by Thomas Midgley and C. F. Kettering.

1939
First successful semi-hermetic (Copelametic) compressor introduced by the Copeland Company. Sales started in 1939. It was a field serviceable compressor.

1935–1965
A number of chlorofluorocarbons (CFCs) were developed during this period.

1985



Stratospheric ozone hole discovered.

1974
Professors Rowland and Molina presented the "ozone theory" that CFCs were depleting the ozone layer.

1990
Clean Air Act amendments. Production freezes and bans on certain refrigerants. Signed by President George H. W. Bush, November, 1990.

1989
Montreal Protocol ratified by 100 countries.

1994
Mandatory EPA technician certification required to service refrigeration and A/C equipment or to buy ozone-depleting refrigerants as of November, 1994.

1992
EPA
The EPA made it illegal to intentionally vent CFC and HCFC refrigerants into the atmosphere.

1995
Unlawful to intentionally vent alternative refrigerants (HFCs and all refrigerant blends) into the atmosphere as of November, 1995.

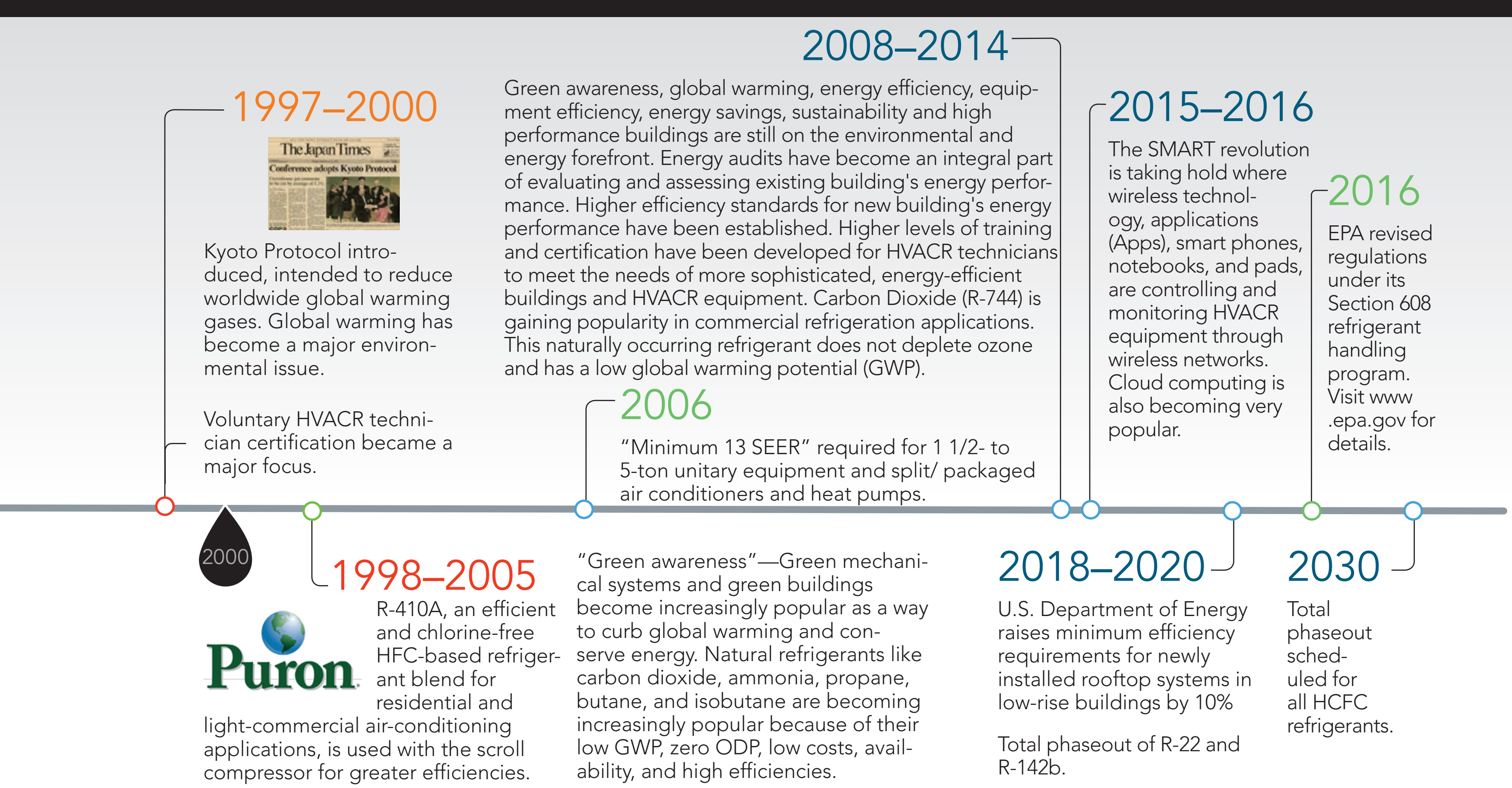
1996
Gradual HCFC production phaseout schedule with the total phaseout of HCFC refrigerants in the year 2030. Phaseout of CFC refrigerants.

- 2004—35% reduction in HCFC refrigerant production.
- 2007—HCFC reduction on production was accelerated from 65% to 75% from the baseline 1989 production year.
- 2010—HCFC-22 is banned in new equipment. No production or importing of HCFC-22 and HCFC-142b, except for use in equipment manufactured before January 1, 2010.
- 2015—90% reduction in HCFC-22 production from the baseline production year of 1989. No production or importing of any HCFC, except for use in equipment manufactured before January 1, 2010.
- 2016—EPA updates regulations on refrigerant handling and usage.
- 2018—EPA expands sales restrictions on HFC and HFO refrigerants. Daily fine for intentionally venting refrigerant increases to $44,539.
- 2019—New refrigerant leak inspection, verification test, and record-keeping requirements go into effect.
- 2020—Total ban on HCFC-22 production. No production and no importing of R-22 and R-142b.
- 2030—Total ban on all HCFC production. No production and no importing of any HCFC.

From 1997 to 2000, voluntary HVACR technician certification became a major focus of the industry. From 1998 to the present, the major players in voluntary HVACR technician certification and home-study examinations were, and continue to be, the AC&R Safety Coalition, the Air-Conditioning, Heating and Refrigeration Institute (AHRI), the Heating, Air Conditioning, and Refrigeration Distributors International (HARDI), the Carbon Monoxide Safety Association (COSA), the Green Mechanical Council, HVAC Excellence, North American Technician Excellence (NATE), the Refrigeration Service Engineers Society (RSES), and the United Association of Journeymen and Apprentices (UA).

By 2008, global warming had become a major environmental issue. A scoring system was designed to help engineers, contractors, and consumers know the "green value" of each mechanical installation. R-410A, an efficient and chlorine-free HFC-based refrigerant blend for residential and light-commercial air-conditioning applications was developed for use with the scroll compressor for greater efficiencies. Also today, every central split cooling system manufactured in the United States must have a Seasonal Energy Efficiency Ratio (SEER) rating of at least 13. This energy requirement was mandated by federal law as of January 23, 2006. The "green value" encompasses the system's energy efficiency, pollution output, and **sustainability**. Green buildings and green mechanical systems are becoming increasingly popular in today's world as a way to curb global warming.

Green awareness, global warming, energy efficiency, energy savings, sustainability, and high-performance buildings are still at the forefront of environmental and energy concerns. Energy audits have become an integral part of



evaluating and assessing the energy performance of existing buildings. Higher efficiency standards for the performance of new buildings have been established.

GREEN AWARENESS

As mentioned, global warming stemming from the uncontrolled rate of greenhouse gas emissions is a major global environmental issue. Most of the sun's energy that reaches the earth is in the form of visible light. After passing through the atmosphere, part of this energy is absorbed by the earth's surface and is converted into heat energy. The earth, warmed by the sun, radiates heat energy back into the atmosphere toward space. Naturally occurring gases and lower atmospheric pollutants such as CFCs, HCFCs, HFCs, carbon dioxide, carbon monoxide, water vapor, and many other chemicals absorb, reflect, and/or refract the earth's infrared radiation and prevent it from escaping the lower atmosphere. Carbon dioxide, mainly from the burning of fossil fuels, is a major contributor to global-warming. The gases in the atmosphere slow the earth's heat loss, making the earth's surface warmer than it would be if heat energy had passed unobstructed through the atmosphere into space. The warmer earth's surface then radiates more heat until a balance is established between incoming and outgoing energy. This warming process is called **global warming** or the **greenhouse effect**. Humans are chiefly responsible for producing many of the greenhouse gases that are causing environmental problems.

Over 70% of the earth's fresh water supply is either in ice cap or glacier form. Scientists are concerned that these ice caps or glaciers will melt if the average earth temperature rises too much, thereby increasing ocean water levels. The scientific consensus is that we must limit the rise in global temperatures to less than 3.6°F (2°C) above pre-industrial levels to avoid disastrous impacts. An increase of 2°C will likely displace millions of people from their homes due to rising water levels. Food production will decline, rivers will become too warm to support marine life, coral reefs will die, snow packs will decrease and threaten water supplies, weather will become unpredictable and extreme, and many plant and animal species will die and become extinct.

Nineteen of the hottest 20 years on record have occurred in the past 20 years and the four warmest years on record have all occurred since 2014 (information obtained from www.climate.gov). Atmospheric carbon dioxide levels are now at their highest. Half of the world's oil is gone and other natural resources are dwindling. The average American uses about 140 gallons of water per day, and in some regions of the country, water supplies are drying up. Because of this, slowing, and possibly stopping or even reversing, the growth rate of greenhouse gas emissions has become a global effort.

Buildings are the major source of demand for energy and materials, and they are also the major source of greenhouse gases that are attributed to the by-products of energy use and materials. At the time of this writing, there are nearly 6 million commercial buildings and over 138.5 million housing units in the United States. Surprisingly, almost every one of their mechanical systems is obsolete. The global-warming scares, the rising price of fuels, the scarcity of clean water, and the ever-growing waste stream demand improvements in our homes and businesses today. Trained contractors, with the help of the government, installers, builders, manufacturers, and educators, must renovate and improve the efficiency of these buildings and mechanical systems.

In the United States, buildings account for approximately

- 36% of total energy used,
- 65% of electrical consumption,
- 30% of greenhouse gas emissions,
- 30% of raw materials used,
- 30% of waste output (136 million tons annually), and
- 12% of potable water consumption.

Organizations like the Green Mechanical Council (GreenMech) and the United States Green Building Council (USGBC) are setting goals for the use of fewer fossil fuels in existing and new buildings. Some of these goals are listed here:

- All new buildings, developments, and major renovation projects must be designed to use one-half of the fossil-fuel energy they would typically consume.
- The fossil-fuel reduction standard for all new buildings must be increased to
  - 70% in 2015,
  - 80% in 2020, and
  - 90% in 2025.
- By 2030, new buildings must be carbon-neutral, which means that they cannot use any greenhouse-gas-emitting fossil-fuel energy to operate.
- Joint efforts must be made to change existing building standards and codes to reflect these targets.

Builders can accomplish these goals by choosing proper siting, building forms, glass properties and locations, and materials and by incorporating natural heating, cooling, ventilating, and lighting strategies. Renewable energy sources such as solar, wind, biomass, and other carbon-free methods can operate equipment within the building.

Leadership in Energy and Environmental Design (LEED) is a voluntary internationally recognized green building certification system for developing high-performance, sustainable buildings, which is referred to as the LEED Green Building Rating System. It was established by the USGBC in 1999 and is widely recognized as a third-party verification system and guideline for measuring what constitutes a green building. At the time of this printing, there are more than 79,000 projects participating in the LEED program worldwide. Over 200,000 individuals presently possess the LEED AP, LEED Green Associate, or LEED Fellow credential.

The USGBC membership, which is composed of every sector of the building industry and consists of over 9000 organizations, developed and continues to refine LEED. LEED promotes expertise in green building by offering project certification, professional accreditation, and training. LEED emphasizes state-of-the-art strategies for sustainable site development, water savings, energy efficiency, material selection, and indoor environmental quality. According to the United Nations World Commission on Environment and Development, a **sustainable design** "meets the needs of the present without compromising the ability of future generations to meet their own needs." Companies looking to utilize **green** technologies or incorporate sustainable design into their buildings and facilities, are concerned with six areas:

- Optimizing site location
- Optimizing energy use
- Protecting and conserving water
- Using environmentally preferable products
- Enhancing indoor environmental quality
- Optimizing operational and maintenance practices

There are multiple LEED rating categories that include:

- Building Design and Construction—For new construction or major renovations; includes New Construction, Core & Shell, Schools, Retail, Hospitality, Data Centers, Warehouses & Distribution Centers, and Healthcare.
- Interior Design and Construction—For complete interior fit-out projects; includes Commercial Interiors, Retail and Hospitality.
- Building Operations and Maintenance—For existing buildings that are undergoing improvement work or little to no construction; includes Existing Buildings, Schools, Retail, Hospitality, Data Centers, and Warehouses & Distribution Centers.
- Neighborhood Development—For new land development projects or redevelopment projects containing residential uses, nonresidential uses, or a mix. Projects can be at any stage of the development process, from conceptual planning to construction; includes Plan and Built Project.
- Homes—For single-family homes, low-rise multifamily (one to three stories) or mid-rise multifamily (four to six stories); includes Homes and Multifamily Lowrise and Multifamily Midrise.
- Cities and Communities—For entire cities and sub-sections of a city. Using the Arc performance platform, LEED for Cities projects can measure and manage their city's water consumption, energy use, waste, transportation, and human experience.

Visit https://new.usgbc.org/leed for more information on the LEED program.

Points are awarded in each category depending on how well the building meets the category's requirements. There are four levels of certification according to the point system:

Certified	40–49
Silver	50–59
Gold	60–79
Platinum	80–110

The purpose of LEED is to provide a third-party certification process using nationally developed and accepted minimum standards for the construction industry. It affects the design, construction, and operation phases of high-performance "green" buildings. LEED systems take into account other ways of increasing efficiencies, such as water conservation, **heat island** reduction in urban areas, incentives for use of locally manufactured materials, site preparation, and maintenance. To receive a LEED rating, the facility must be built by a team, some of whose members are LEED accredited professionals. LEED-rated projects have a higher cost than similar, non-LEED projects because the enhancements required to increase efficiencies and the certification and documentation required cost more. Many European nations have made LEED-type systems mandatory for all buildings and have instituted existing-building rating systems that monitor yearly energy consumption of all utilities in these buildings. The higher a building's energy usage or "energy utilization index" above a minimum consumption, the higher amount of penalty tax the building owner must pay. This provides an incentive for improving the building's energy footprint.

The green awareness movement isn't just a temporary "buzzword" that will fade away with time. It is one that will be rapidly gaining momentum in the coming years. If contractors want to remain competitive, they must obtain the necessary training with regard to green building and LEED certification.

An alternative to LEED certification is the Green Globes® program, which is offered by the Green Building Initiative. The Green Globes program operates on a 1000-point scale and certifications range from one to four Green Globes, with four Green Globes being their highest possible rating. Both the LEED and Green Globes programs are nationally accepted.

HISTORY OF HOME AND COMMERCIAL HEATING

Human beings' first exposure to fire was probably when lightning or another natural occurrence, such as a volcanic eruption, ignited forests or grasslands. After overcoming the fear of fire, early humans found that placing a controlled fire in a cave or other shelter could create a more comfortable living environment. Fire was often carried from one place to another. Smoke was always a problem, however, and methods needed to be developed for venting it outside. Native

Americans, for example, learned in later years to vent smoke through holes at the peak of their tepees, and some of these vents were constructed with a vane that could be adjusted to prevent downdrafts. The fireplaces common in Europe and North America were vented through chimneys.

Early stoves were found to be more efficient than fireplaces. These early stoves were constructed of a type of firebrick, ceramic materials, or iron. In the mid-eighteenth century, a jacket for the stove and a duct system were developed. The stove could then be located at the lowest place in a structure, and the heated air in the jacket around the stove would rise through a duct system and grates into the living area. This was the beginning of the development of circulating warm-air heating systems.

Boilers that heated water were also developed, and this water was circulated through pipes in duct systems. The water heated the air around the pipes, and the heated air passed into the rooms to be heated. Radiators were then developed. The heated water circulated by convection through the pipes to the radiators, and heat was passed into the room by radiation. These early systems were forerunners of modern hydronic heating systems.

Steam heat became a popular heating option at the beginning of the nineteenth century and coal was the fuel of choice for boilers. Coal was desirable because it burned hot and lasted a long time. But coal was not inexpensive and the coal dust that was ever-present resulted in health, primarily breathing, problems for many people. In the late 1920s, the oil burner was invented and was a very attractive alternative to coal. Oil was less expensive and cleaner than coal and nobody had to keep feeding coal to keep the fire burning.

Oil remained popular, and inexpensive, until the Arab oil embargo of 1973 and the Iranian Revolution in 1979. Oil prices spiked and people had to wait in lines, sometimes for hours, to get their ration of fuel for their cars. As a result, many people switched to natural gas, comprised primarily of methane. Natural gas boilers began to replace the old oil boilers, just as oil had replaced coal.

After the price shocks of the 1970s, oil prices stayed low for most of the 1980s and 1990s, with occasional moderate peaks. Oil prices then rose steadily from the period between September 11, 2001 and 2009, and continue to fluctuate today.

Today, commercial and residential heating needs are being met in a number of ways that include traditional hot water and steam, but new, more efficient technologies are becoming more attractive. These include radiant heating, radiant cooling, and geothermal heat pump systems.

CAREER OPPORTUNITIES

The HVACR industry is rapidly changing due to advancements in technology being spurred on by the need for increased energy efficiencies. The career opportunities available in HVACR for those who have acquired formal technical training coupled with field experience are unlimited. Schools that provide excellent technical training in the field are becoming easier to identify through HVACR program accreditation. As new equipment becomes more technically challenging and the existing workforce continues to age, the employment positions available will continue to outnumber applicants for the foreseeable future. This shortfall in available, competent HVACR service technicians is being addressed through the cooperative efforts of educational institutions, labor unions, employers, and manufacturers. Many organizations offer apprenticeship opportunities that can lead to high-income positions. Manufacturers are also teaming up with select educational institutions across North America to help develop the next generation of HVACR technicians.

Many newer buildings are constructed so tightly that the quality of the air must be controlled by specialized equipment. The conditions of the air must also be carefully controlled in areas that perform manufacturing processes. Heating and air-conditioning systems control the temperature, humidity, and total air quality in residential, commercial, industrial, and other types of buildings. Refrigeration systems are used to store and transport food, medicine, and other perishable items. Refrigeration and air-conditioning technicians design, sell, install, or maintain these systems. Many contractors and service companies specialize in commercial refrigeration. The installation and service technicians employed by these companies install and service refrigeration equipment in supermarkets, restaurants, hotels/motels, flower shops, and many other types of retail and wholesale commercial businesses.

Other contractors and service companies may specialize in air-conditioning. Many specialize in residential-only or commercial-only installation and service; others may install and service both residential and commercial equipment up to a specific size. Air-conditioning may include cooling, heating, humidifying, dehumidifying, ventilating, exhausting, and air cleaning. Heating equipment may rely on fossils fuels, such as natural gas, liquefied petroleum, or oil, or may be configured as electric-based or heat pump systems. The type and number of installations will vary from one part of the country to another, depending on the climate and availability of the heat source. The heating equipment may be either a furnace (which heats air) or a boiler (which heats water). The boiler heats water and pumps it to the space to be heated, where one of many types of heat exchangers transfers the heat to the air.

Technicians may specialize in installation or service of equipment, or they may be involved with both. Other technicians may design installations or work in the sales area. Sales representatives may be in the field selling equipment to contractors, businesses, or homeowners; others may work in wholesale supply stores. Still other technicians may represent manufacturers, selling equipment to wholesalers and large contractors.

Many opportunities exist for technicians to be employed in the industry or by companies owning large buildings. Technicians may be responsible for the operation of air-conditioning equipment, or they may be involved in the service of this equipment. Opportunities also exist for employment in servicing household refrigeration and room air conditioners, which would include refrigerators, freezers, and window or through-the-wall air conditioners. Opportunities are also available for employment in a field often called transport refrigeration. This includes servicing refrigeration equipment on trucks or on large containers hauled by trucks and ships.

Most modern houses and other buildings are constructed to keep outside air from entering, except through planned ventilation. Consequently, the same air is circulated through the building many times. The quality of this air may eventually cause a health problem for people spending many hours in the building. This indoor air quality (IAQ) presents another opportunity for employment in the air-conditioning field. Technicians clean filters and ducts, take air measurements, check ventilation systems, and perform other tasks to help ensure healthy air quality. Other technicians work for manufacturers of air-conditioning equipment. These technicians may be employed to assist in equipment design, in the manufacturing process, or as equipment salespersons.

Following is a list of many career opportunities in the HVACR field:

- Field service technician
- Service manager
- Field supervisor
- Field installer
- Journeyman
- Project manager
- Job foreman
- Application engineer
- Controls technician
- Draftsperson
- Contractor
- Lab technician
- Inspector
- Facilities technician
- Instructor
- Educational administrator
- Inside/outside sales rep
- Sales manager
- New product developer
- Research engineer
- Estimator

TECHNICIAN CERTIFICATION PROGRAMS

HISTORY

Even though mandatory technician certification programs are in place today, the EPA originally did not consider them as its lead option. As a matter of fact, the EPA initially thought private incentives would ensure that technicians were properly trained in refrigerant recycling and recovery. The EPA also stated that it would play an important role through a voluntary technician certification program by recognizing those who provide and participate in voluntary technician training programs that meet certain minimum standards. The EPA also thought that a mandatory certification program would be an administrative burden. The EPA then requested public comments on a mandatory versus voluntary technician certification program. More than 18,000 comments were in favor of a mandatory program, and only 142 were in favor of a voluntary program. Most of the 18,000 in favor of the mandatory certification program were major trade organizations and technicians themselves. Manufacturers of recovery and recycling equipment, along with environmental organizations, also supported mandatory certification. They believed it would increase compliance with venting, recovery, and recycling laws and the general safe handling of refrigerants. The following were reasons given by those favoring mandatory technician certification:

- Improve refrigerant leak detection techniques
- Promote awareness of problems relating to venting, recovery, and recycling of refrigerants
- Improve productivity and cost savings through proper maintenance practices
- Ensure environmentally safe service practices
- Gain more consumer trust
- Receive more liability protection
- Ensure that equipment is properly maintained
- Educate technicians on how to effectively contain and conserve refrigerants
- Create uniform and enforceable laws
- Foster more fair competition in the regulated community

With these comments in mind, the EPA decided that mandatory technician certification would increase fairness by ensuring that all technicians were complying with today's rules. The EPA also said that a mandatory certification program would enhance the EPA's ability to enforce the rules by providing a tool to use against intentional noncompliance: the ability to revoke the technician's certification. The EPA then created a mandatory technician certification program that mandated all technicians to be certified effective November 14, 1994.

All technicians must pass an examination administered by an approved EPA testing organization in the private sector in order to purchase refrigerant and to work on equipment that contains refrigerant. This mandatory certification applies to individuals who work as installers, contractor employees, in-house service personnel, and anyone else who installs, maintains, or repairs equipment that might reasonably have the opportunity to release CFCs or HCFCs into the atmosphere. The EPA created three separate technician certification types:

- Small appliances
- High- and very high pressure appliances
- Low-pressure appliances

Persons who successfully pass a *core of questions* on stratospheric ozone protection and legislation and also pass one of the three certifications are certified in that category. If all three certifications are passed, a person will be *universally* certified. To date, the EPA is not requiring recertification. However, it will be the technicians' responsibility to keep up to date on new technologies and governmental rule changes. By creating types of certification, the EPA allowed technicians to be tested on information concerning equipment and service practices that the technicians primarily service and maintain.

Although training programs are beneficial, participation in a training program is not required currently. To create price-competitive training programs, training programs requested by technicians will be administered by the private sector. Many national educational and trade organizations—such as the AC&R Safety Coalition, the Air-Conditioning, Heating and Refrigeration Institute (AHRI), the Air Conditioning Contractors of America (ACCA), the Heating, Air Conditioning, and Refrigeration Distributors International (HARDI), the Carbon Monoxide Safety Association (COSA), the Educational Standards Corporation (ESCO), the Environmental Protection Agency (EPA), Ferris State University (FSU), the Green Mechanical Council (GreenMech), HVAC Excellence, North American Technician Excellence (NATE), the Refrigeration Service Engineers Society (RSES), and the United Association of Journeymen and Apprentices (UA)—have developed training and/or testing programs. These programs are specifically intended to help technicians comply with the July 1, 1992, refrigerant venting law. Unit 9 of this text, "Refrigerant and Oil Chemistry and Management—Recovery, Recycling, Reclaiming, and Retrofitting," gives more detailed information on the EPA's mandatory technician certification program, including details on the specific types of certification tests and specifications.

CERTIFICATION PROGRAMS

Technician certification programs can be divided into two categories:

- Mandatory technician certification programs
- Voluntary technician certification programs

Mandatory technician certification programs are covered in the preceding paragraphs and in Unit 9. Voluntary technician certification programs are becoming popular because they are industry-led and are much more comprehensive in nature when compared to mandatory certification programs. They give technicians an educational opportunity from the beginning to the end of their careers. These programs allow technicians to become recognized for their level of expertise and also allow them to achieve higher levels of competence. Their diverse nature allows almost every aspect of the industry to be covered. Voluntary certification testing is based on the courses taken for each level, with an outline and roadmap on what material will be covered on the test and where to find it. An example of a voluntary certification is the ESCO Group's R-410A Safety and Certification test, which evaluates a candidate's knowledge of the special considerations that must be taken into account when working on systems that contain this refrigerant.

WHY TECHNICIANS SHOULD BECOME CERTIFIED

As mentioned, mandatory technician certification allows the technician to purchase ozone-depleting refrigerants legally and work on equipment that contains refrigerant. Some advantages of having both mandatory and voluntary technician certifications are:

- Customers tend to ask for certified technicians because of their reliability and good workmanship.
- Equipment manufacturers develop faith in certified technicians and have a sense of well-being when they know the job has been accomplished by a certified technician.
- Higher standards are set on the job by certified technicians, giving them more respect, recognition, trust, higher pay, and a higher quality of life in the long run.
- Employers would rather hire a certified technician, because they know certified technicians care more about their reputation, customer relations, and overall professionalism.
- Certification gives the technician a status symbol for other technicians to work up to.
- Certified technicians have proven technical proficiencies with measured capabilities.

PROGRAMMATIC ACCREDITATION

Accreditation has gained popularity in the last decade for secondary and postsecondary HVACR programs. Program accreditation involves an independent, nongovernmental, nonindustry, third-party review of an educational program. At the time of this printing, the leading HVACR programmatic accreditation agency is HVAC Excellence (www.escogroup.org). The programmatic accreditation process validates that the established standards of excellence for HVACR educational programs are met or, in many cases, exceeded. These standards are designed to ensure that our future workforce receives the quality of training required to provide the skills necessary for success in the HVACR industry. The Department of Education in its Code of Federal Regulations, Title 34, sets guidelines and defines criteria for who can be an accredited body but does not do any accrediting itself.

The standards require a thorough examination of the programs:

- Mission
- Curriculum
- Plans of instruction
- Finances and funds
- Administrative responsibilities
- Equipment and tools
- Facilities
- Instructor's qualifications

Programmatic accreditation provides an HVACR program with an opportunity to recognize both its strengths and weaknesses. Some of the benefits of programmatic accreditation include the following:

- Enhanced student confidence in the quality of the program
- Assurance and confidence of employers that student graduates are properly trained
- Enhanced student placement and employer satisfaction
- Acceptability of transfer credits for students
- Self-evaluation of faculty and staff
- Enhanced articulation agreements with other HVACR programs and institutions
- Assistance in acquiring federal, state, and private funding
- Creation of self-improvement goals

NATIONAL SKILL STANDARDS

The National Skill Standards (NSS), as interpreted by the Vocational-Technical Education Consortium of States (VTECS) for Heating, Air Conditioning, and Refrigeration Technicians, were funded by the U.S. Department of Education from 1992 to 1998 as part of twenty-two projects from the National Skill Standards Board. The NSS were created by a joint effort of committees composed of heating, air-conditioning, and refrigeration industry professionals. These skill standards not only help technicians identify the skills and knowledge needed for their occupation but also assess their weaknesses and/or needs for additional training.

Skill standards are often described as workplace behaviors, technical skills, and the general body of knowledge required of technicians to be successful, productive, and competitive in today's workforce. As HVACR manufacturers increase the efficiency and sophistication of their equipment, technicians require additional, updated information as well as a sound technical skills base to maintain, install, and service this equipment. The increased number of environmental regulations concerning more energy-efficient and environmentally friendly HVACR equipment have also created a new knowledge and skills base for technicians to learn and use on their jobs. Although it is difficult to provide all users of this text with information on the vast array of issues covered in the NSS, the authors have made every effort to do so. We hope both private and public institutions as well as the industry will use our comprehensive book to provide both students and workers with the competencies needed for successful employment and advancement in the ever-changing and growing technical HVACR field.

The NSS are divided into three main areas with subdivisions as follows:

CORE KNOWLEDGE

- Communications
- Mathematics
- Science

OCCUPATIONAL-SPECIFIC SKILLS

- Core skills
- Occupational-specific skills

WORKPLACE BEHAVIORS

- Ethics
- Environment
- Communications
- Professionalism
- Problem solving

The *core skills* consist of:

- Safety and environment
- Electrical principles
- Electric motors
- Controls
- Refrigeration principles and practices
- Heating principles and practices
- Air-conditioning principles and practices
- Piping principles and practices

The *occupational-specific skills* consist of:

- Residential and light-commercial heating
- Residential and light-commercial air-conditioning
- Residential and light-commercial heat pumps
- Commercial conditioned-air systems
- Commercial refrigeration

CUSTOMER RELATIONS AND TECHNICIAN SOFT SKILLS

Customer relations are extremely important to a service business and consequently to a service technician. Without customers there will be no business and no income. The technician is a major factor in acquiring and keeping customers. This is true whether work is performed at a residence, an office, a restaurant, or a store, or whether the technician is an inside or outside salesperson for a distributor or contractor. The HVACR business and technician are dependent on the customers. All technicians should be concerned with the quality of their work because customers have the right to insist on quality. If they have had a previous unsatisfactory experience, customers may have some doubt as to whether they will get the quality service for which they are paying. As professionals, technicians should strive to provide the best workmanship possible. Quality work will prove beneficial to the technician, to the company, and to the consumer. Customers depend on the technician for their comfort and air quality at home and at the office.

FIRST IMPRESSIONS

The impression the technician makes on the customer is very important, and the first impression is the most important. The first impression begins with the technician arriving on time. Most customers feel that their time is valuable. If the technician is going to be delayed, the customer should be called and given an explanation. An appointment should be scheduled for either later that day or another time convenient for the customer. The customer affected by a delay should be given priority in scheduling a makeup appointment. If the service call is an emergency, all efforts should be made to arrive as soon as possible.

When arriving, do not park in or block the customer's driveway unless necessary. If carrying equipment or having to make several trips to the vehicle, ask permission to park in the driveway. The customer may suggest another location. Ensure that the service vehicle is kept in a neat, clean, and orderly manner. This will help to make a good impression and provide better working conditions for the technician.

Remember the customer's name and use it frequently, preferably with Ms., Mrs., or Mr. Sir or Ma'am may also be used when appropriate. Always make eye contact with the customer and avoid talking to the ground or to a clipboard. Always wear clean clothes. If a company-issued shirt and pants are available, wear them. A name patch bearing your name and the company's name and logo also makes a good first impression. Politely ask the customer how you can help. When meeting a customer, be prepared to shake hands. In many cases, it may be appropriate to let the customer initiate the handshake. Your handshake should be firm and accompanied with a smile. A handshake that is too limp may give the impression of weakness; one that is too strong may indicate an overbearing type of person. Not all people like to shake hands. After ringing the doorbell, always maintain a distance from the door. This gives customers comfortable spacing between them and you. Make sure the customer has invited you in before making a move toward the door. Politely introduce yourself by name and then introduce the company you work for. Hand the customer your business card and then tell the customer the reason for your visit. Be friendly and always have a smile. Make sure you have a pen or pencil to write down any concerns or complicated issues the customer may have. Politely answer any questions asked by the customer. Listed below is a summary of what makes a good first impression:

- Arrive on time.
- Do not park in or block the customer's driveway unless you have permission.
- Keep your service vehicle in a neat, clean, and orderly manner.
- Remember the customer's name.
- Be prepared to shake hands.
- Always make eye contact with the customer.
- Always introduce yourself and your business.
- Tell the customer the reason for your visit.
- Hand the customer your business card.
- Always wear clean clothing.
- Wear a name tag and company logo.
- Be polite to the customer.
- Give the customer a comfortable space once at the door.
- Never enter the house until invited.

APPEARANCE

Another major factor in first impressions and maintaining good customer relations is appearance. It is almost impossible to get a second chance to make a good first impression. As a serviceman moves from one service call to another throughout the day, dirt and grime may start to accumulate on clothing. For this reason, it is important to always keep a spare pair of work pants and shirt in the service truck. Work shoes may need to be wiped clean between service calls to keep them presentable also. Appearance includes the following:

Hair—Brushed or combed, neatly trimmed. Male technicians should be clean-shaven or have a neatly trimmed beard or mustache. Female technicians with longer hair may wish to contain it in a ponytail or pinned back in some fashion.

Clothing—Neat and clean. For most uniforms, ensure that the shirttail is tucked in. A clean and neat uniform will help to make the appropriate impression. If you have an ID badge, wear it in plain sight. Make certain that your clothes are pressed to give that professional appearance.

Personal hygiene—Cleanliness is important. Hands should be washed and clean. A shower before going to bed or before going to work should be a regular habit. Your appearance and personal hygiene are major indicators of your personality and the quality of work you offer.

First impressions are so important that a service technician does not want to ruin a relationship with a customer because of poor appearance. Dirty shoes can be wiped down with a moist towel or rag if necessary. Some companies require that their service personnel put on plastic booties that cover their work boots when they enter the customer's house. Make sure the uniform you are wearing fits. A uniform that is too tight or too loose can make the service technician look uncared for. Long-sleeved shirts should be worn to protect the your arms. Long pants instead of shorts should also be worn to protect the legs and give a neat and tidy appearance. Any tattoos should be covered up by the shirt or pants. Earrings and finger rings should not be worn to work for safety reasons. Even though earrings and tattoos are in style for many younger people, they often give older customers a wrong or negative impression. Always follow the company's policy pertaining to tattoos and earrings shown and/or worn on the job. Also, once finished with your work, make sure the job site is cleaned up.

After arriving at the customer's address take a minute or two to get organized. You may have a clipboard with material to organize and review. Think about what you are going to say and do when meeting the customer. Do not flip a cigarette butt to the ground outside the truck or on the way to the house or other location. There should be no smoking while making a service call. After arriving at the house but before entering, put on your shoe covers. Do not use the customer's phone for personal calls, and do not use the customer's bathroom.

Listed next is a summary of major factors for good customer relations as they pertain to the technician's appearance:

- Make sure hair is brushed or combed neatly, mustache or beards are trimmed, and long hair is contained in a ponytail or pinned up neatly.
- Uniforms and other clothing should be neat, clean, and tucked in.
- A spare, clean uniform should be carried in the service truck.
- Always wipe down work shoes with a clean towel or rag.
- An identification badge should be worn.
- Shower daily and always have clean hands and face.
- Make sure your uniform fits. Never wear a too loose or too tight uniform.
- Take off ear and hand rings while at work.
- Wear long-sleeved shirts and long pants while working.
- Hide any tattoos with shirt or pants if possible.
- Clean up a job site once finished.

COMMUNICATION SKILLS

The technician must be able to describe the service that can be provided; however, the technician must not monopolize the conversation. A big part of communicating is listening. Most people like to be listened to and the more you listen to the customer about the problems involved with the system, the easier it will be to diagnose. Courtesy and a show of respect for the customer should be evident at all times. The training and high skill level of the technician should also be evident as a result of the conversation and the ability to answer and ask questions. Telling people how capable and skilled you are is often a turnoff. Remember to smile often. Ask pertinent questions and do not interrupt when the customer is answering. Never say anything to discredit a competing business.

Never make customers feel stupid because they do not understand a technical topic you are talking about. A service technician should avoid using too many technical terms or concepts. Try to communicate to the customer in everyday language that they can understand. Always ask the customer their account of the problem before starting any work. Politely ask questions to try to expedite your solving the problem. If possible, make customers think that they are part of the solution. Always make sure all of the customer's questions are answered before starting any work. Clearly and concisely explain what work will have to be done and why it has to be done. If the problem has to do with the way the HVACR system is being operated, politely show the customer the proper way the system should be operated. If there are any choices or options on how to operate the equipment, explain the advantages and disadvantages of each option and why each option is important.

In summary, good communication skills consist of

- describing the service that can be provided,
- never monopolizing the conversation,
- being a good listener,
- being courteous and showing respect for the customer,
- never bragging about your training or skills,
- asking the customer pertinent questions,
- never interrupting customers when they are answering your questions or simply talking,
- never making a customer feel stupid about any technical topic,
- using everyday language the customer can understand,
- asking customers for their account of the problem,
- making customers feel that they helped with finding the solution to the problem,
- answering all of the customer's questions before starting any work,
- clearly and concisely explaining what work has to be done and why it has to be done,
- politely showing the customer the proper way to operate any HVACR systems, and
- politely explaining any options for system operations and the advantages or disadvantages of each option.

CONFLICTS AND ARGUMENTS

Conflicts and arguments with customers should be avoided at all costs. When you are dealing with an angry customer, you are dealing with an emotional customer. Listen until the customer is finished before replying. A complaint may be an opportunity to solve a problem. The customer should feel assured that the technician is competent and that the work will be done properly and in a timely manner. Never be critical of a customer, even in a joking manner. People hate to be criticized. It is very important to be friendly.

Even when angry, most customers are good individuals. They may have had a bad experience or may be disappointed, frustrated, and upset. Angry customers may have reviewed what they want to say and will not feel right until they have said it to a willing listener. Be sympathetic, listen carefully, and try to determine why the customer is so upset. Do not take it personally. Do not reply until the customer is definitely finished with the complaint, and then try to concentrate on the solution. Ask the customer what you as the technician can do to help resolve the problem. If you can resolve the problem, do it. If you must report it to your supervisor, let customers know that you will do this right away and will get back to them immediately if possible. After listening carefully to the customer and resolving any complaint to the extent possible, you should be ready to start the troubleshooting process.

One of the best ways to handle an angry customer is to try to calm the customer down by taking on the responsibility yourself. Apologize and assure the customer that the problem will be fixed as soon as possible. Accept the responsibility and try to find answers to the customer's questions.

If you are on a service call with a co-worker, never argue in front of the customer with that co-worker. If you and a co-worker disagree on a topic, discuss the problem outside or in private, and then approach the customer together with a unified front. Arguing in front of a customer with a co-worker ruins the customer's confidence, trust, and credibility in both workers and their company. Even if you and your co-worker never come to an agreement, pretend that you have and tell the customer that you are looking at two possibilities for solving the problem and want to test both. No matter how the customer replies or what is said to you, never take the comments personally and cause a conflict. Always maintain your professionalism. Tell customers that they are valued and you will do your best to try and resolve the problem. Let them know that you, your co-worker, and the company value their business. You may even have to admit in some situations that the company's excellent track record in customer service may have fallen short this time.

Below is a summary of how to handle conflicts and arguments:

- Listen to customers and let them finish talking before replying.
- The customer must feel that the technician is competent.
- Never be critical of a customer, even in a joking manner.
- Be sympathetic, listen carefully, and try to determine why the customer is so upset.
- Do not take anything the customer says personally, and always avoid a conflict.
- Ask what you can do to resolve the problem.
- Try to calm the customer down by accepting the responsibility yourself, and try to find an answer to the customer's questions.
- Never argue with a co-worker in front of a customer.
- Always maintain your professionalism.
- Let customers know that they are valued and you and your company value their business.

THE SERVICE CALL

After arriving and introducing yourself, it is important to ask as many questions as needed to have a clear understanding of the problem. These questions will help to assure the customer that you are capable of solving the problem. During the service procedure you may need to talk with the customer to explain what you have found and to indicate the parts needed and possibly state the approximate costs if they may be higher than expected. If you must leave the job for any reason, tell the customer the reason and when you will return. You may need to go for parts or to another job emergency, but the customer needs to be informed. An informed customer is less likely to become angry or to complain. Keep the customer informed of all unusual circumstances. Double-check all your work. Clean the work site when finished and protect the customer's property from damage.

After the service work is completed, tell the customer what you found wrong, indicate that it has been corrected, and demonstrate when possible by turning the unit on while explaining how the problem was corrected. Customers deserve to know what they are paying for. All discussions should be in terms the customer will understand. Before leaving, give billing information to the customer. This should include a description of the work done and the costs.

Listed next is a summary of how the technician should handle a service call:

- Politely introduce yourself.
- Politely ask questions of the customer to make sure you clearly understand the problem.
- Politely explain to the customer the problems found, parts needed, and the approximate cost of fixing the problem.
- If temporarily leaving the job site, inform the customer of a return time and a reason for leaving.
- Inform the customer of any unusual circumstances.
- Double-check your work.
- Clean the work site when finished.
- Protect the customer's property from damage.
- Explain to the customer how the problem was corrected.
- Before leaving, give billing information to the customer, including a work description and the costs.

THE TECHNICIAN AS A SALESPERSON

A good technician is also a good salesperson. All options to resolve a problem should be presented in an honest and fair manner. Most customers are honest about why they are calling your company. It makes no sense for them to lie, because your time is their money. The faster you can fix the problem, the less money it will cost them in most cases. A service technician should never lie about a service problem or the price of fixing the problem. Even though customers may be disappointed with the truth, if they find out the service technician has lied about the problem, respect will be lost and satisfaction will not be gained. A customer will never be satisfied with a lie. An HVACR company will not be around very long if it is not truthful and ethical. With the truth, a customer always knows where he stands. Even though the truth may hurt at first because it is not what the customer wants to hear, it is a temporary situation. Provide estimates and work orders in writing. A customer is buying not only service or equipment but also a solution to a problem. The customer may be offered an option not necessarily required but should not be "talked into it." The sale and installation of a new system is not always the best option for a customer. If a customer feels that he or she was talked into something that was not needed, there is a good chance that the transaction will end the relationship between the customer and the company. A company may have written recommendations for guiding the technician in presenting options. For instance if a unit is "x" years old and the repair will cost "x" amount, a recommendation to replace the unit or system may be appropriate.

In summary, what makes a technician a good salesperson is the following:

- Present all problem-solving options honestly and fairly.
- Provide estimates and work orders in writing.
- Never talk the customer into something that is not needed.
- Written company guidelines should be followed by the technician in presenting service or installation options.

UNIT 1

HEAT, TEMPERATURE, AND PRESSURE

OBJECTIVES

After studying this unit, you should be able to

- define temperature.
- make conversions between the Fahrenheit and Celsius scales.
- describe molecular motion at absolute zero.
- define the British thermal unit.
- describe heat flow between substances at different temperatures.
- explain the transfer of heat by conduction, convection, and radiation.
- describe sensible heat, latent heat, and specific heat and provide examples of each.
- state atmospheric pressure at sea level and explain why it varies at different elevations.
- describe the purpose and operation of a barometer.
- explain inches of Mercury, psig, and psia as they apply to pressure measurements.
- convert absolute pressures to gauge pressures and vice versa.
- convert pressure readings in inches of Mercury to absolute pressures and vice versa.

SAFETY CHECKLIST

- ☑ Heating, ventilation, air conditioning and refrigeration technicians are often exposed to very high and very low temperatures. Be sure to wear gloves and other appropriate pieces of personal protection equipment (PPE) to reduce the chances of getting injured.
- ☑ Many fluids that are used by the HVACR technicians are under pressure. Be sure to transport all pressure vessels vertically and be sure they are properly secured.
- ☑ Make certain that all tanks are properly capped to prevent accidental releases from the tanks.
- ☑ Make certain all test instruments are properly calibrated and fully operational to ensure accurate pressure and temperature readings.
- ☑ Make certain to properly store all test instruments when not in use to prevent damage.

1.1 HEAT, TEMPERATURE, AND PRESSURE

The terms **heat**, hot, and cold are often used to describe many things in our daily lives such as comfort, food, beverages, and weather. We experience heat waves and cold fronts. We drink hot tea and cold water. *Hot* and *cold* are relative terms used to describe the temperature of something with respect to some imaginary or unknown temperature. This "unknown" temperature varies from one individual to the next, so the terms hot and cold are highly subjective. Consider the situation where the temperature in a particular city has stayed in the −20°F range for two weeks straight and then, one day, the temperature reaches +30°F. The residents of the city get so happy, they start proclaiming how hot it is outside and shed their winter coats. Many may argue that 30°F is not hot but, when exposed to −20°F temperatures for so long, a 30°F temperature can appear to be a heatwave.

In the HVACR industry, the terms *hot* and *cold* are too general and, for the most part, undefined. For example, the word *cold* simply refers to the absence of heat. Those working in this industry need to be more specific when referring to heat and how heat energy is transferred within and between substances. When we need to be more specific, we often refer to **temperature**. Saying that it is 95 degrees outside is much more specific than simply saying that it is hot outside. Imagine trying to bake a cake with a recipe that instructs you to preheat the oven until it's hot.

In our industry, accurate temperature readings are very important because it is based on these temperature readings that we make decisions regarding system operation. Therefore, it is important to use high-quality thermometers to take these readings, **Figure 1.1**. It is important to understand that *heat* and *temperature* are not the same thing and cannot be used interchangeably. The following pages provide more details about heat and temperature.

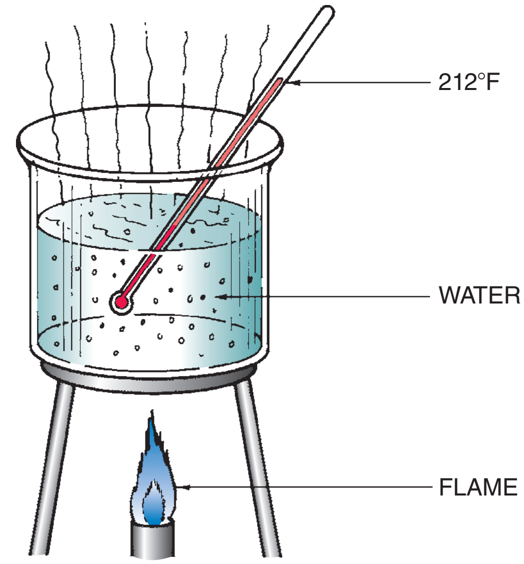
Another term that must be understood is **pressure**. We use the term **atmospheric pressure** when we refer to weather conditions. We also refer to pressure when we talk about the air in the tires of bicycles and cars. Information regarding the pressures inside air-conditioning and refrigeration systems is very important to the HVACR technician. System operating pressures, along with various temperature readings, provide valuable information to the technician that is used to properly evaluate and troubleshoot heating and cooling equipment. System pressures are obtained by using a refrigeration gauge manifold, **Figure 1.2**.

The terms *heat*, *pressure*, and *temperature* will be a part of nearly all conversations relating to the HVACR industry, so it's very important to understand them. The sections that follow provide more insight into these concepts and how they relate to each other.

Figure 1.1 Thermocouple thermometer used to take accurate temperature readings in heating, air-conditioning, and refrigeration systems. Photo by Eugene Silberstein

Figure 1.2 Pressure gauge used to measure operating pressures in air-conditioning and refrigeration equipment. Photo by Eugene Silberstein

Figure 1.3 The water in the container increases in temperature because the molecules move faster as heat is applied. When the water temperature reaches 212°F, boiling will occur.



1.2 TEMPERATURE

Temperature can be thought of as the level of **heat intensity**. The level of heat intensity should not be confused with the amount of heat, or heat content. As more heat is transferred to a substance, the molecular motion within the substance increases and, as a result, its temperature increases.

Most people know that the freezing point of water is 32°F and that the boiling point is 212°F, **Figure 1.3**. These points are commonly indicated on a thermometer, which is an instrument that measures temperature. However, these temperatures are only accurate when standard atmospheric conditions exist. For example, in Denver, Colorado, which is about 5600 feet above sea level, water boils at about 203°F. At the top of Mt. Everest, which is about 31,000 feet above sea level, water boils at about 167°F. Standard conditions occur at sea level with the barometer reading 29.92 in. Hg (14.696 psia). This topic is covered later in this unit as part of the discussion of pressure. It is important to understand the concept of standard conditions because these are the conditions that will be applied to actual practice later in this book.

Heat theory states that the lowest attainable temperature is −460°F. This is the temperature at which all molecular motion stops and the temperature at which there is no heat present. This temperature is referred to as absolute zero. This is a theoretical temperature because molecular motion has never been totally stopped. Scientists have actually come very close, getting within one-millionth of a degree of absolute zero in a laboratory setting.

Throughout the world, there are two commonly used temperature scales. The Fahrenheit temperature scale is part of the English measurement system used by the United States. This measurement system is also known as the I-P, or inch-pound, system. The Celsius temperature scale is part of the International System of Units (SI) or *metric system* used by most of the world. Some Fahrenheit and Celsius equivalent temperatures are provided in **Figure 1.4**. A more detailed conversion chart can be found in Appendix B of this book.

If we have a Celsius temperature that we want to convert to a Fahrenheit temperature, we can use the following formula:

$$°F = (1.8 \times °C) + 32°$$

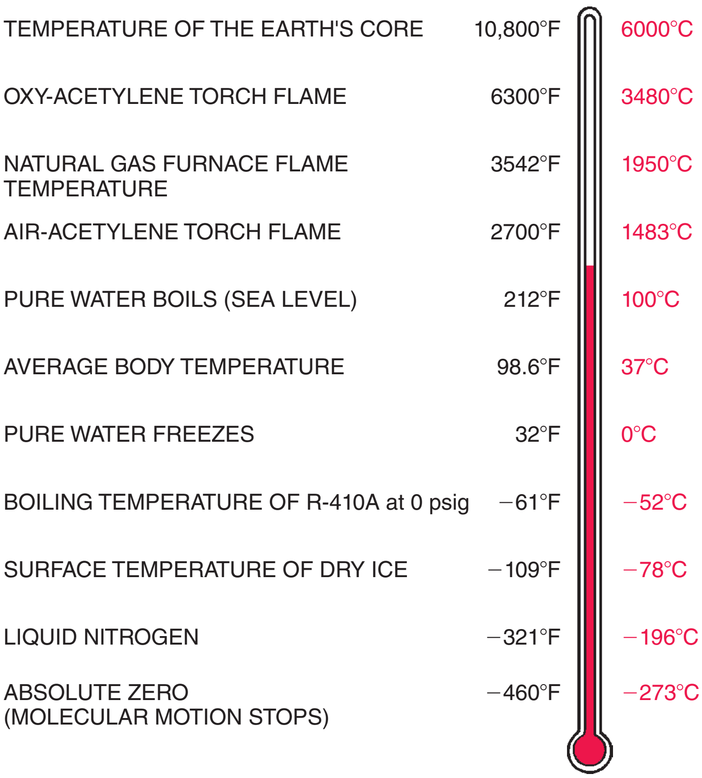


Figure 1.4 Fahrenheit and Celsius equivalent temperatures.

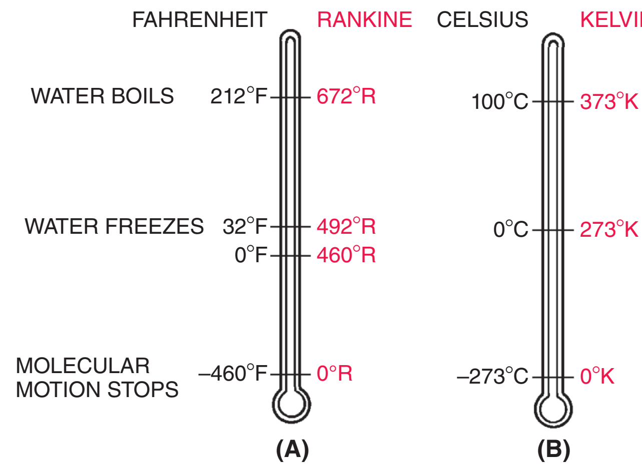


Figure 1.5 (A) A Fahrenheit and Rankine thermometer. (B) A Celsius and Kelvin thermometer.

For example, if we had a Celsius temperature of 20°C, we can determine the equivalent Fahrenheit temperature by plugging the Celsius value into the formula to get:

$$°F = (1.8 \times °C) + 32°$$
$$°F = (1.8 \times 20°C) + 32°$$
$$°F = 36° + 32°$$
$$°F = 68°$$
$$\text{So, } 20°C = 68°F$$

If we have a Fahrenheit temperature that we want to convert to a Celsius temperature, we can use the following formula:

$$°C = (°F - 32°) \div 1.8$$

For example, if we had a Fahrenheit temperature of 50°F, we can determine the equivalent Celsius temperature by plugging the Fahrenheit value into the formula to get:

$$°C = (°F - 32°) \div 1.8$$
$$°C = (50°F - 32°) \div 1.8$$
$$°C = 18° \div 1.8$$
$$°C = 10°$$
$$\text{So, } 50°F = 10°C$$

Up to this point, temperature has been expressed in everyday terms. It is equally important in the HVACR industry to refer to temperature in engineering and scientific terms. Performance ratings of equipment are established using **absolute** temperatures. Performance ratings allow for easy comparison among equipment produced by different manufacturers. The Fahrenheit absolute scale is called the **Rankine** scale (named for W. J. M. Rankine), and the Celsius absolute scale is known as the **Kelvin** scale (named for scientist Lord Kelvin). Absolute temperature scales use zero as their lowest value and start where molecular motion starts. For instance, 0 on the Fahrenheit absolute scale is called absolute zero or 0° Rankine (0°R). Similarly, 0 on the Celsius absolute scale is called absolute zero or 0° Kelvin (0°K), **Figure 1.5**.

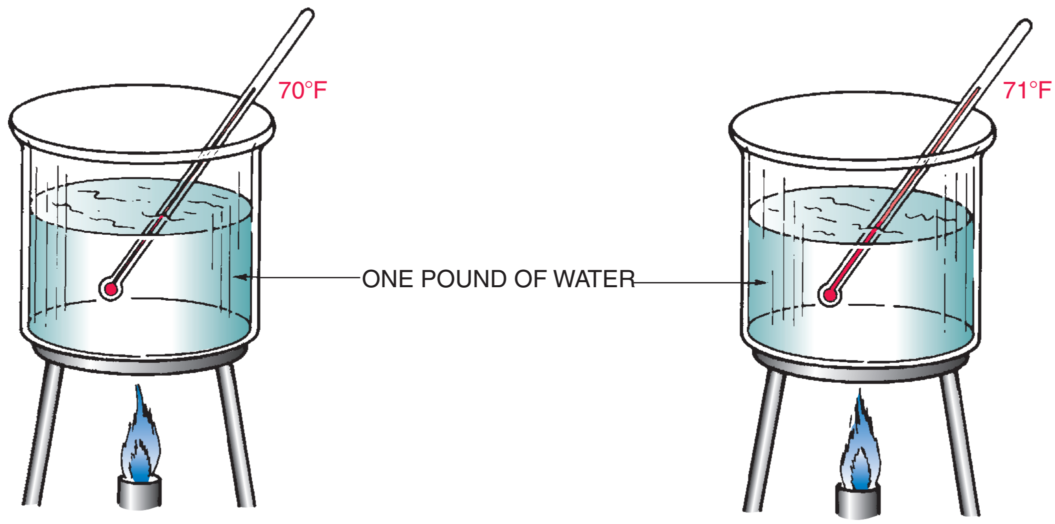
1.3 INTRODUCTION TO HEAT

The laws of thermodynamics can help further our understanding of heat. The first law of thermodynamics states that energy can be neither created nor destroyed, but can be converted from one form to another. This means that the "production" of heat energy is actually the conversion of other forms of energy, such as fossil fuels (gas and oil).

Temperature describes the level of heat intensity with reference to absolute zero, which was discussed earlier. The term used to describe the *quantity of heat energy* or heat content is the **British thermal unit (Btu)**, which indicates how much heat energy is contained in a substance. The rate of heat transfer can be determined by considering the time it takes to transfer a certain amount of heat energy. Air-conditioning and heating equipment is rated in Btu/h, where the "h" represents "hour." For example, an air-conditioning system operating at a rated capacity of 24,000 Btu/h has the ability to remove 24,000 Btu of heat energy from the structure every hour.

The Btu is defined as the amount of heat required to raise the temperature of 1 pound (lb) of water 1°F. For example, when 1 lb of water (about 1 pint) is heated from 70°F to 71°F,

Figure 1.6 One British thermal unit (Btu) of heat energy is required to raise the temperature of 1 lb (pound) of water 1°F.

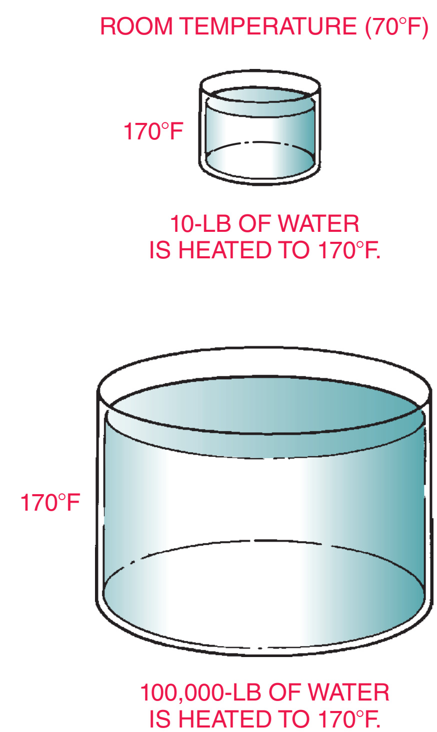


1 Btu of heat energy is absorbed into the water, **Figure 1.6**. When a temperature difference exists between two substances, a transfer of heat between the substances will occur. The next three sections in this unit address three common types of heat transfer, namely conduction, convection, and radiation. The temperature difference between two substances is the driving force behind heat transfer. The greater the temperature difference, the greater the heat transfer rate. Heat flows naturally from a warmer substance to a cooler substance. Rapidly moving molecules in the warmer substance give up some of their energy to the slower-moving molecules in the cooler substance. The warmer substance cools because the molecules have slowed. The cooler substance becomes warmer because the molecules are moving faster. So, the next time you pour warm soda into a glass filled with ice, remember that the ice isn't making the soda cold, the soda is making the ice hot!

The following example illustrates the difference between the quantity of heat and the level of heat. Consider a tank that contains 10 pounds of water at room temperature, which is about 70°F. If the water in the tank is to be heated to 170°F, 1000 Btu of heat energy must be added to the water (100 degrees × 10 pounds = 1000 Btu). Now consider a tank that contains 100,000 pounds of water at room temperature. If the water in this tank is to be heated to 170°F, 10,000,000 Btu of heat energy must be added to the water (100 degrees × 100,000 pounds = 10,000,000 Btu), **Figure 1.7**. So, even though the initial and final temperatures are the same in both situations, the water in the larger tank contains much more heat energy than the water in the smaller tank. In addition, the water in the larger tank will cool down much slower than the water in the smaller tank. This is because there is much more heat energy stored in the water in the larger tank.

Another water-related example may be helpful in differentiating between the level of heat intensity and the quantity of heat. Consider a 200-ft-deep well and a large lake with a water depth of 25 ft. Although the level of water is higher in the well than in the lake, these depth measurements cannot be used to determine the quantity of water present in either the well or the lake. The depth of water (in feet) tells us the level of water, but it in no way expresses the quantity (gallons) of water. In a similar manner, temperature relates to the level of heat, not the quantity of heat energy.

Figure 1.7 More heat energy is required to heat larger amounts of a substance.



In practical terms, a piece of heating equipment is rated according to the amount of heat it will produce in a given time period. If the equipment had no such rating, it would be difficult for a buyer to choose the correct appliance. The rating of a gas or oil-fired furnace used to heat a home is permanently printed on the appliance's nameplate. Either furnace would be rated in Btu per hour, which is a *rate* at which heat energy is transferred into the structure. For now, it is sufficient to say that if a house loses, on average, 75,000 Btu of heat per hour, the selected furnace should be rated at 75,000 Btu/h. If a smaller furnace is chosen, the house will begin to get cold any time the heat loss of the house exceeds the Btu/h output of the furnace.

To describe the absence of heat, the term *cold* is often used. Because heat is expressed as a positive value in relation to no heat, cold is really an expression of comparison with no numerical value. When a person says it is cold outside, the term is being used to express a relationship to the normal expected temperature for the time of year or to the inside temperature. Cold is sometimes referred to as a "level of heat absence."

1.4 CONDUCTION

Heat transfer by **conduction** can be explained as the energy actually traveling from one molecule to another within a substance. As a molecule moves faster, it causes the nearby molecules to do the same. For example, if one end of a copper rod is placed in a flame, in a short time the other end will get hot as well. The heat travels up the rod from molecule to molecule, **Figure 1.8**. Heat transfer by conduction is used in many applications. For example, heat is transferred by conduction from the hot electric burner on the cookstove to the pan or pot resting on it.

Heat does not conduct through all materials at the same rate. Copper, for instance, conducts heat at a different rate than iron. Glass is a very poor conductor of heat. Touching a wooden fence post or another piece of wood on a cold morning does not give the same sensation as a metallic surface on a car or other piece of steel. Although the steel might feel colder than the wood, in reality, the steel is not colder. Steel is a better conductor of heat than wood and, as such, causes heat to travel out of the hand at a faster rate, **Figure 1.9**. The sensation of cold is actually the feeling we experience when heat is *leaving* our body. When we get a fever, we often experience chills. This is partly due to an elevated body temperature that increases the rate of heat transfer from the body.

Figure 1.8 The copper rod is held in the flame only for a short time before heat is felt at the far end.

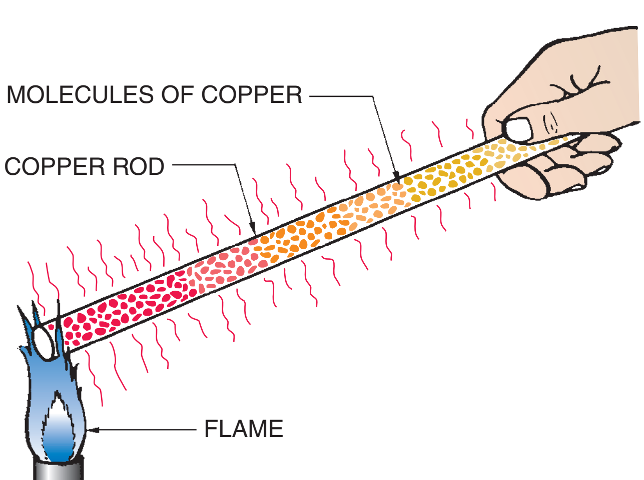
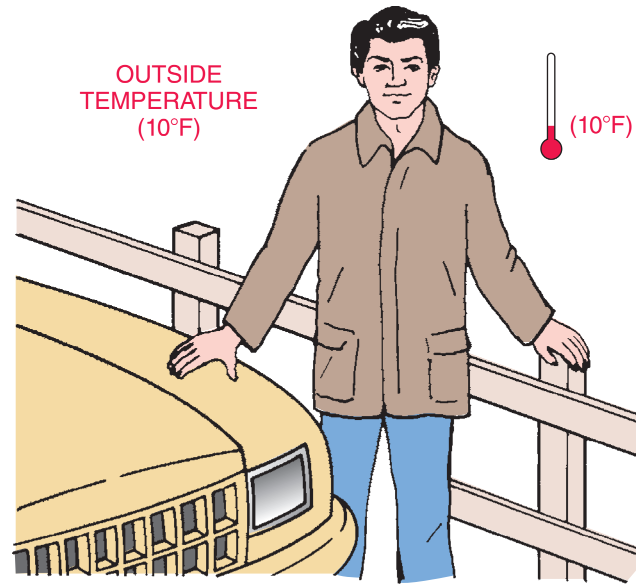


Figure 1.9 The car fender and the fence post are actually the same temperature, but the fender feels colder because the metal conducts heat away from the hand faster than the wooden fence post.



The different rates at which various materials conduct heat have an interesting similarity to the conduction of electricity. As a rule, substances that are poor conductors of heat are also poor conductors of electricity. For instance, copper is one of the best conductors of electricity and heat, and glass is one of the poorest conductors of both. Glass is actually used as an insulator in some electrical applications. The properties of electrical conductors will be discussed in Unit 12, "Basic Electricity and Magnetism."

1.5 CONVECTION

Heat transfer by **convection** relies on a fluid flow, such as air or water, to move heat from one location to another. Many large buildings have a central heating plant that heats water and pumps it throughout the building to the spaces to be heated. Notice the similarity between the words *convection* and *convey* ("to carry from one place to another"). Convection can be classified as either forced or natural. Forced convection utilizes fans, blowers, or pumps to move the fluid, while natural convection refers to the fluid's natural tendencies to flow.

A gas-fired furnace is an example of forced convection because air from the conditioned space is drawn to the appliance by a blower. The air then passes over the furnace's heat exchanger, which transfers heat from the burning fuel to the air. The air is then forced into the ductwork and distributed to the various rooms in the structure. **Figure 1.10** shows this process in which 70°F room air is entering the furnace; 130°F air is leaving; and the blower is creating the pressure difference to force the air into the various rooms. The blower, as mentioned, provides the **forced convection**.

Figure 1.10 Air from the room enters the blower at 70°F. The blower forces the air across the hot heat exchanger and out into the structure at 130°F.

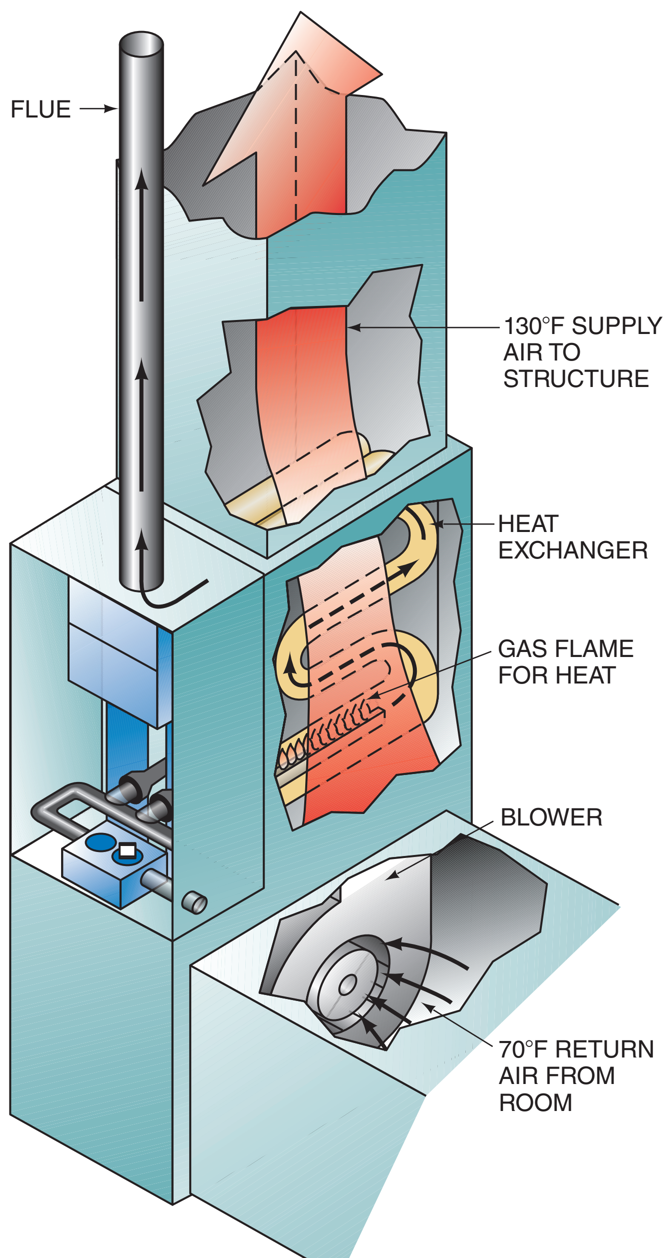
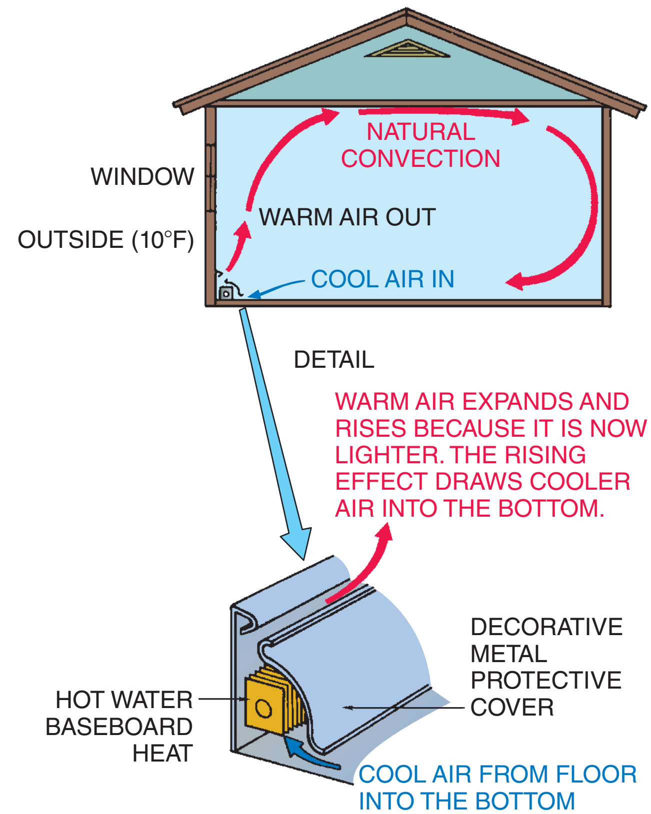


Figure 1.11 Natural convection occurs when heated air rises and cool air takes its place.

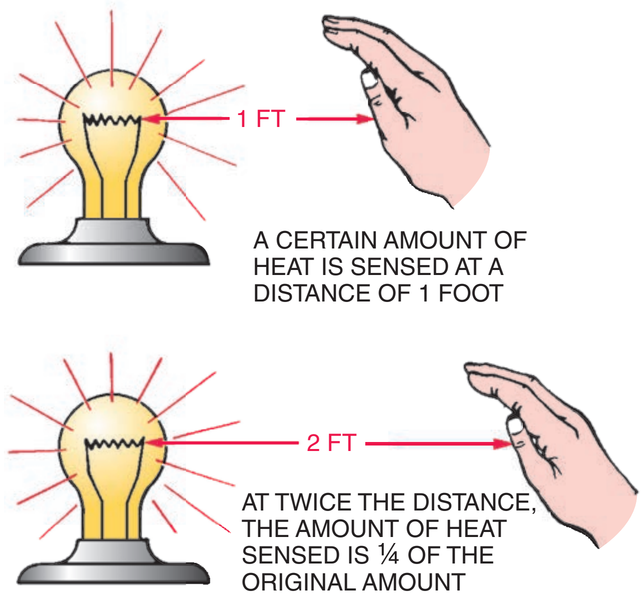


Another example of heat transfer by convection occurs when heated air rises naturally. This is referred to as **natural convection**. When air is heated, it expands, and the warmer air becomes lighter than the surrounding unheated air. This principle is applied in many ways in the air-conditioning industry. Sections of baseboard heaters are an example. When the air near the floor is heated, it expands and rises. This heated air is replaced by cooler air around the heater, which sets up a natural convection current in the room, **Figure 1.11**.

1.6 RADIATION

Heat transfer by **radiation** can best be explained by using the sun as an example of the heat source. The sun is approximately 93 million miles from earth's surface, yet we can feel its intensity. Heat transferred by radiation travels through space without heating it and is absorbed by the first solid object that it encounters. Radiation is the only type of heat transfer that can travel through a vacuum, such as space, because it is not dependent on matter as a medium of heat

Figure 1.12 The intensity of the radiant heat diminishes by the square of the distance.



transfer. Convection and conduction require some form of matter to be the transmitting medium. The earth does not experience the total heat of the sun because heat transferred by radiation diminishes by the inverse of the square of the distance traveled. In practical terms, this means that every time the distance is doubled, the heat intensity decreases by a factor of 4. If you hold your hand close to an incandescent light bulb, for example, you feel the heat's intensity, but if you move your hand twice the distance away, you will feel only one-fourth of the heat intensity, **Figure 1.12**. Keep in mind that, because of the inverse-square-of-the-distance rule, radiant heat does not transfer the actual temperature or heat quantity value. If it did, the earth would be as hot as the sun.

Electric heaters that glow red hot are practical examples of radiant heat. The red-hot electric heater coil radiates heat into the room. It does not heat the air, but it warms the solid objects that the heat rays encounter. Any heater that glows has the same effect.

1.7 SENSIBLE HEAT

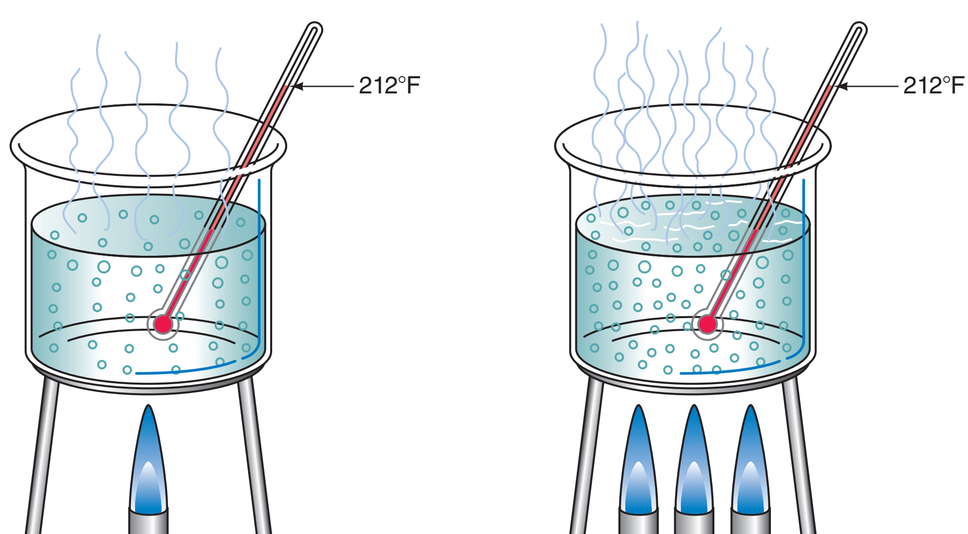
Heat level or heat intensity can readily be measured when it changes the temperature of a substance (remember the example of changing 1 lb of water from 70°F to 71°F). This change in the heat level can be measured with a thermometer. When a change of temperature occurs, we know that the level of heat or heat intensity has changed. This is called **sensible heat**.

1.8 LATENT HEAT

Not all changes in heat content result in a change of temperature. Some heat transfers result in a change of state with no temperature change. Such heat transfers are referred to as **latent** or **hidden heat** transfers. An example of a latent heat transfer is any additional heat that is added to water while it is boiling in an open container. Once water is brought to the boiling point, adding more heat only makes it boil faster; it does not raise the temperature of the water, **Figure 1.13**.

There are three other terms that are important to understand when referring to latent heat transfers: **latent heat of vaporization, latent heat of condensation**, and **latent heat of fusion**. Latent heat of vaporization is the amount of

Figure 1.13 Adding three times as much heat only causes the water to boil faster. The water does not increase in temperature.



heat energy, in Btu/lb, required to change a substance into a vapor. For example, the latent heat of vaporization for water at atmospheric conditions is 970.3 Btu/lb. For ease of calculation, we often round this value to 970 Btu/lb. This means that if we have 1 lb of water at 212°F that we want to change to 1 lb of steam at 212°F, we would need to *add* 970 Btu of heat energy to the water.

Latent heat of condensation is the amount of heat energy, in Btu/lb, required to change a vapor into a liquid. This is, in effect, the opposite of latent heat of vaporization. For example, the latent heat of condensation for steam at atmospheric conditions is 970.3 Btu/lb. If we had 1 lb of steam at 212°F that we wanted to change to 1 lb of water at 212°F, we would need to *remove* 970 Btu of heat energy from the steam.

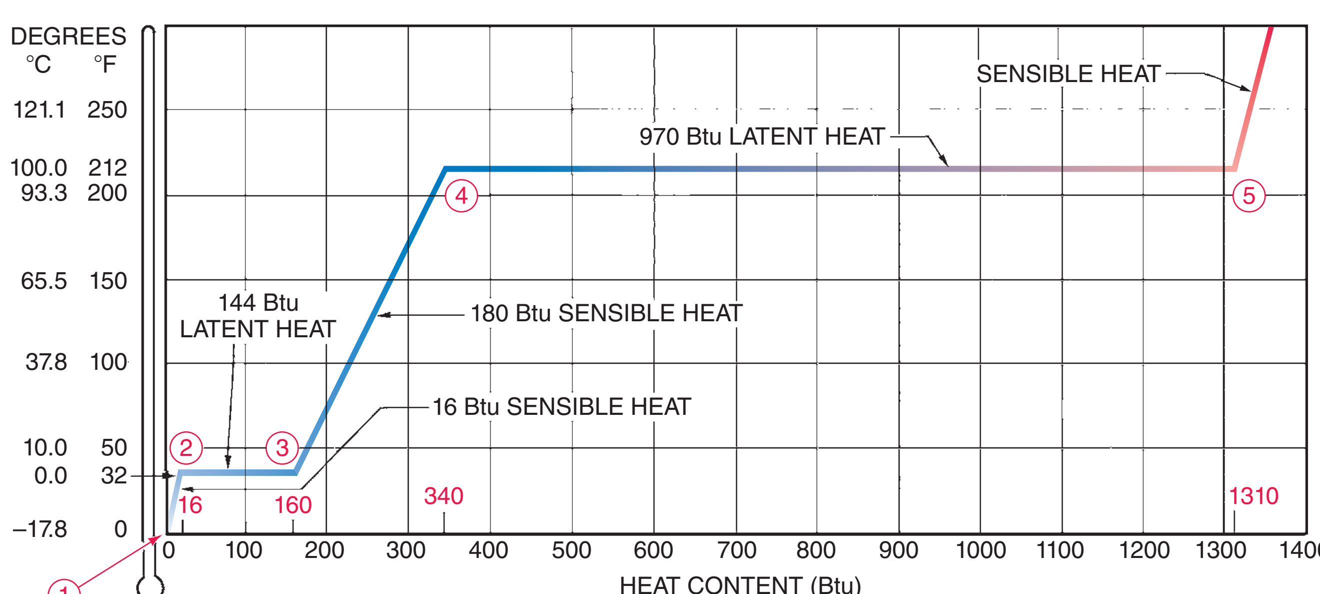
Latent heat of fusion is the amount of heat energy needed to change the state of a substance from a solid to a liquid or from a liquid to a solid. The latent heat of fusion for water is 144 Btu/lb. If we had 1 lb of ice at 32°F under atmospheric conditions, we would have to add 144 Btu of heat energy to the ice in order to melt it. If, on the other hand, we had 1 lb of water at 32°F under atmospheric conditions, we would have to *remove* 144 Btu of heat energy from the water in order to freeze it.

The following example describes the sensible heat and latent heat characteristics of 1 lb of water at standard atmospheric pressure from 0°F through the temperature range to above the boiling point. In the chart in **Figure 1.14** notice that temperature is plotted on the vertical axis, and the amount of heat energy added to the water/ice/steam throughout the example is plotted along the horizontal axis, along the bottom of the chart. Since no heat is added at the start of this example, the heat content scale starts (at point 1) at zero Btu/lb. As heat is added, the temperature will rise, except during latent- or hidden-heat processes.

The following statements should help you to understand the chart:

1. Water is in the form of ice at point 1 where the example starts. Remember that point 1 is *not* absolute zero. Point 1 represents ice at 0°F and is used as a starting point. Since no heat has been added to the ice at point 1, the heat content, as read on the heat content scale along the horizontal axis, is zero.
2. From point 1 to point 2, 16 Btu of heat energy has been added to the ice. As can be seen in the diagram, after the addition of this heat, the temperature of the ice is now 32°F. This is a sensible heat transfer because there was a measurable temperature change. Since it took 16 Btu of heat energy to raise the temperature of the ice from 0°F to 32°F, we can conclude that it takes only 0.5 Btu of heat energy to raise the temperature of 1 lb of ice 1°F.
3. When point 2 is reached, the temperature of the ice is 32°F. This is the highest temperature at which ice can exist. If more heat is added, it will be latent heat and the ice will start to melt. Because this is a latent heat transfer, the temperature of the ice will not increase. Adding 144 Btu of heat will change the 1 lb of ice to 1 lb of water at 32°F.

Figure 1.14 The heat/temperature graph for 1 lb of water at atmospheric pressure explains how water responds to heat. An increase in sensible heat causes a rise in temperature. An increase in latent heat causes a change of state, for example, from solid ice to liquid water.



4. When point 3 is reached, the substance is now 100% water. At this point, a total of 160 Btu of heat energy has been added. 16 Btu raise the temperature of the ice from 0°F to 32°F and 144 Btu to melt the ice. Adding more heat to the water at this point will result in will cause a rise in temperature. (This is sensible heat.) Removal of any heat at point 3 results in some of the water changing back to ice. This is described as removing latent heat because there is no change in temperature.
5. Between points 3 and 4, 180 Btu of heat have been added. The water has been heated from 32°F to 212°F, which is a 180°F (212°F − 32°F = 180°F) rise. Referring back to the definition of the Btu, you will see that it takes 1 Btu of heat energy to raise the temperature of 1 lb of water 1°F. So, a 180°F temperature rise will require 180 Btu of heat energy. At point 4 a total of 340 Btu of heat energy has been added to the process (16 Btu + 144 Btu + 180 Btu).
6. Point 4 represents the 100% saturated liquid point. The water is saturated with heat to the point that the addition of any more heat will cause the water to boil (a latent heat process) and start changing to a vapor (steam). If any heat is removed from the water at this point, it will simply cool to a temperature that is lower than 212°F. Adding 970 Btu of heat energy causes the 1 lb of liquid to boil, becoming vapor.
7. Point 5 represents the 100% saturated vapor point. The water is now in the vapor state. Heat removed would be latent heat and would change some of the vapor back to a liquid. This is called *condensing the vapor.* Any heat added to the process after point 5 is sensible heat; it raises the vapor temperature above the boiling point, which is called *superheating*. Any water vapor with a temperature above the boiling point of 212°F is superheated vapor. The concept of superheat will be important in future studies. Note that in the vapor state it takes only 0.5 Btu to heat the water vapor (steam) 1°F, the same as when water was in the ice (solid) state.

Between points 1 and 5, a total of 1310 Btu of heat energy has been added to the process. A summary of the process is provided here:

Process	Latent or Sensible	# of Btu	State/Temperature Change
Point 1 to Point 2	Sensible Heat Transfer	16 Btu	Ice at 0°F to Ice at 32°F
Point 2 to Point 3	Latent Heat Transfer	144 Btu	Ice at 32°F to Water at 32°F
Point 3 to Point 4	Sensible Heat Transfer	180 Btu	Water at 32°F to Water at 212°F
Point 4 to Point 5	Latent Heat Transfer	970 Btu	Water at 212°F to Steam at 212°F

1.9 SPECIFIC HEAT

We now realize that different substances respond differently to heat. When 1 Btu of heat energy is added to 1 lb of water, it changes the temperature 1°F. This holds true only for water; other heated substances have different values. For instance, we noted that adding 0.5 Btu of heat energy to either ice or steam (water vapor) caused a 1°F rise per pound. The temperatures of ice and steam increased at twice the rate of water. Adding 1 Btu of heat energy to one pound of either ice or steam would result in a 2°F rise. This difference in heat rise is known as **specific heat**.

Specific heat is the amount of heat necessary to raise the temperature of 1 lb of a substance 1°F. Every substance has a different specific heat. Note that the specific heat of water is 1 Btu/lb/°F. See **Figure 1.15** for the specific heat of some other substances.

1.10 SIZING HEATING EQUIPMENT

Specific heat is significant because the amount of heat required to change the temperatures of different substances

Figure 1.15 Specific heat values for some common substances.

SUBSTANCE	SPECIFIC HEAT Btu/lb/°F	SUBSTANCE	SPECIFIC HEAT Btu/lb/°F
Air	0.24 (Average)	Ice	0.504
Aluminum	0.214	Iron	0.129
Beef, lean	0.77	Kerosene	0.50
Building Brick	0.20	Marble	0.21
Concrete	0.156	Pork, fresh	0.68
Copper	0.092	Seawater	0.94
Cucumbers	0.97	Steam	0.5
Eggs	0.76	Steel	0.116
Gold	0.0312	Water	1.00

is used to size equipment. Recall the example of the house and furnace earlier in this unit. The following example shows how this would be applied in practice. A manufacturing company may need to buy a piece of heating equipment to heat steel before it can be machined. The steel may be stored outside in the cold at 0°F and need preheating before machining. The desired metal temperature for the machining process is 70°F. How much heat must be added to the steel if the plant wants to process 1000 pounds of steel each hour?

The steel is coming into the plant at a fixed rate of 1000 lb/h, and heat has to be added at a steady rate to stay ahead of production. **Figure 1.15** gives a specific heat of 0.116 Btu/lb/°F for steel. This means that 0.116 Btu of heat energy must be added to 1 lb of steel to raise its temperature 1°F. The following formula can be used to determine the total amount of heat required to heat the steel in preparation for processing:

$$Q = W \times \text{Specific Heat} \times \Delta T$$

where Q = quantity of heat needed, W = weight of the substance, ΔT = change in temperature. Substituting in the formula, we get:

$Q = 1000\ \text{lb/h} \times 0.116\ \text{Btu/lb/°F} \times (70°\text{F} - 0°\text{F})$
$Q = 1000\ \text{lb/h} \times 0.116\ \text{Btu/lb/°F} \times 70°\text{F}$
$Q = 8120$ Btu/h required to heat the steel for machining.

The previous example has some known values and an unknown value to be found. The known information is used to find the unknown value with the help of the formula. The formula can be used when adding heat or removing heat and is often used in heat-load calculations for sizing both heating and cooling equipment.

1.11 PRESSURE

Pressure is defined as force per unit of area. This is normally expressed in pounds per square inch (psi). Simply stated, when a 1-lb weight rests on an area of 1 square inch (1 in^2), the pressure exerted downward is 1 psi. Similarly, when a 100-lb weight rests on a 1-in^2 area, 100 psi of pressure is exerted, **Figure 1.16**. If the 100-lb weight rested on a surface that was 100 in^2, the pressure exerted would be 1 psi.

When you swim under the surface of the water, there is a pressure pushing inward on your body. This pressure is the result of the weight of the water. You would feel a different sensation when flying in an unpressurized airplane cabin. Your body would be subjected to less pressure instead of more, yet you would still feel uncomfortable. It is easy to understand why the discomfort under water exists, the weight of the water pushes in. In the airplane, the situation is just the reverse. There is less pressure high in the sky than down on the ground. The pressure is greater inside your body and is pushing out.

Water weighs 62.4 pounds per cubic foot (lb/ft^3). A cubic foot (7.48 gal) of water exerts a downward pressure of 62.4 lb/ft^2 when in actual cube (12 in. × 12 in. × 12 in.) shape. How much weight is then resting on 1 in^2? The answer is simply calculated. The bottom of the cube has an area of 144 in^2 (12 in. × 12 in.) sharing the weight. Each square inch has a total pressure of 0.433 lb (62.4 ÷ 144) resting on it. Thus, the pressure at the bottom of the cube is 0.433 psi, **Figure 1.17.**

A volume of 1 ft^3 is equivalent to 1728 in^3 (12 in. × 12 in. × 12 in. = 1728 in^3), so the dimensions of the container can be changed as long as the volume remains the same. If the same 1 ft^3 of water had the shape shown in **Figure 1.18** (24 in. × 24 in. × 3 in. = 1728 in^3), the pressure at the bottom would be different. The area at the bottom would be 576 in^2, since the base is 24 in. by 24 in. (24 in. × 24 in. = 576 in^2). The resulting pressure would then be only

Figure 1.16 Both weights are resting on a 1-square-inch (1-in^2) surface. One weight exerts a pressure of 1 psi; the other a pressure of 100 psi.

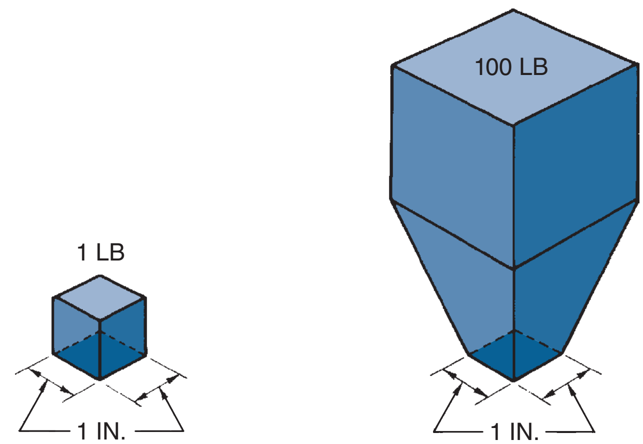


Figure 1.17 One cubic foot (1 ft^3) of water exerts a downward pressure of 62.4 lb/ft^2 on the bottom surface area of a cube.

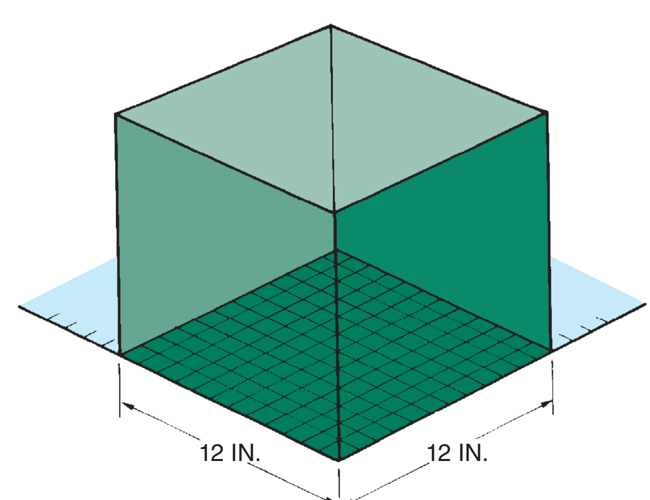
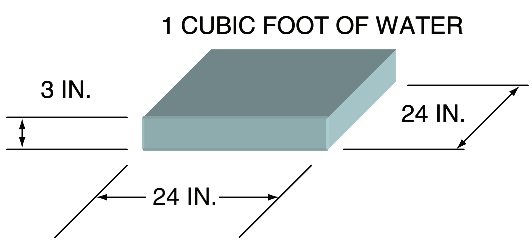


Figure 1.18 If the bottom surface is 4 ft^2, or 576 in^2, the downward pressure is 0.108 psi.



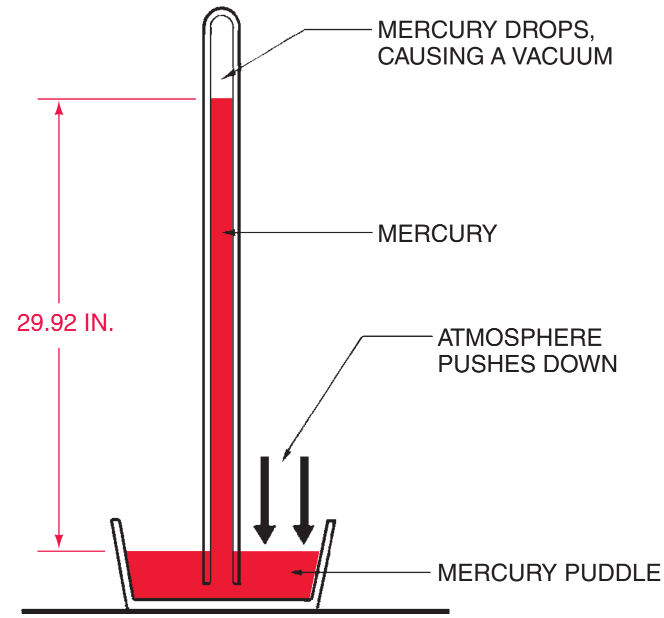
0.108 psi (62.4 ÷ 576). As the base gets larger, the pressure it exerts in the downward direction gets lower. Have you ever seen someone walking across the snow wearing snowshoes? The purpose of the snowshoes is to increase the size of the base to lower the pressure pushing down. This reduces the chance of sinking into the snow.

1.12 ATMOSPHERIC PRESSURE

The sensation of being underwater and feeling the pressure of the water is familiar to many people. The earth's atmosphere is like an ocean of air that has weight and exerts pressure. The earth's surface can be thought of as being at the bottom of this ocean of air. Different locations are at different depths. For instance, there are sea-level locations such as Miami, Florida, or mountainous locations such as Denver, Colorado. The atmospheric pressures at these two locations are different. For now, we will assume that we live at the bottom of this ocean of air. The atmosphere that we live in has weight just as water does, but not as much. Actually earth's atmosphere exerts a weight or pressure of 14.696 psi at sea level. This is known as a standard condition.

Atmospheric pressure can be measured with an instrument called a barometer, which is a glass tube about 36 in. long that is closed on one end and filled with mercury. It is then inserted open-side-down into a puddle of mercury and held upright. The mercury will try to run down into the puddle, but it will not all run out. This is because the atmosphere is pushing down on the puddle, and a vacuum is formed in the top of the tube. At sea level the mercury in the tube will fall to 29.92 in. when the surrounding atmospheric temperature is 70°F, **Figure 1.19**. This is a standard that is used for comparison in engineering and scientific work. If the barometer is located at a higher elevation, such as on a mountain, the mercury column will start to fall. It will fall about 1 in./1000 ft of altitude. When the barometer is at standard conditions and the mercury drops, the weather forecaster will talk about a low-pressure system; this means the weather is going to change. Listening closely to weather reports will make these terms more meaningful. A low-pressure weather system is often associated with

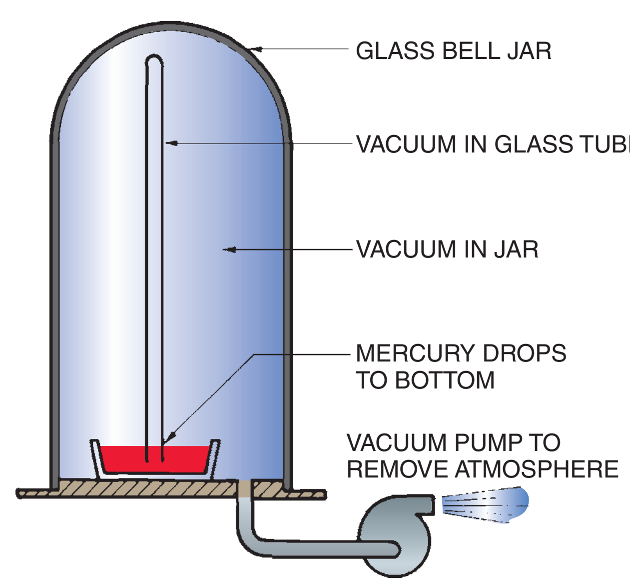
Figure 1.19 Mercury (Hg) barometer.



cloudy, rainy, or snowy conditions, while a high-pressure system is associated with drier weather.

If the barometer is placed inside a closed jar and the air in the jar is removed, the mercury column will fall to the level of the puddle at the bottom, **Figure 1.20**. When the atmosphere is allowed back into the jar, the mercury again rises because a vacuum exists above the mercury column in the tube.

Figure 1.20 When the mercury barometer is placed in a closed glass jar (known as a bell jar) and the atmosphere is removed from the jar, the column of mercury drops to the level of the puddle in the dish.



The mercury in the column has weight and counteracts the atmospheric pressure of 14.696 psi at standard conditions. A pressure of 14.696 psi, then, is equal to the weight of a column of Mercury (Hg) 29.92 in. high. The expression "inches of mercury" thus becomes an expression of pressure and can be converted to pounds per square inch. The conversion factor is 1 psi = 2.036 in. Hg (29.92 ÷ 14.696); 2.036 is often rounded off to 2 (30 in. Hg ÷ 15 psi).

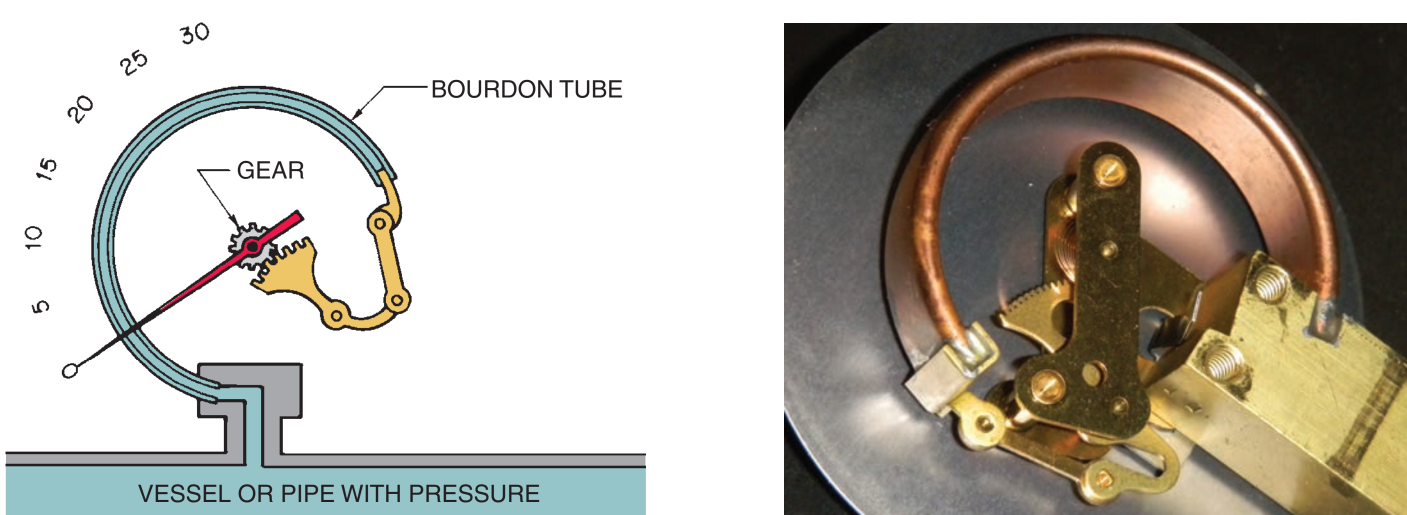
1.13 PRESSURE GAUGES

Measuring pressures in a closed system requires a different method—the **Bourdon tube**, **Figure 1.21**. The Bourdon tube is linked to a needle and can measure pressures above and below atmospheric pressure. A common tool used in the refrigeration industry to take readings in the field or shop is a combination of a low-pressure gauge (called the **low-side gauge**) and a high-pressure gauge (called the **high-side gauge**), **Figure 1.22**. The gauge on the left reads pressures above and below atmospheric pressure and is called a **compound gauge**. The gauge on the right will read up to 500 psi and is called the **high-pressure (high-side) gauge**. **SAFETY PRECAUTION:** *Working with temperatures that are above or below body temperature can cause skin and flesh damage. Proper protection, such as gloves and safety glasses,* **must be used**. *Pressures that are above or below the atmosphere's pressure can cause bodily injury. A vacuum can cause a blood blister on the skin. Pressure above atmospheric can pierce the skin or inflict damage when blowing air lifts small objects like filings.*•

These gauges read 0 psi when opened to the atmosphere. If they do not, then they should be calibrated to 0 psi. The gauges are designed to read psig (pounds-per-square-inch gauge pressure). Atmospheric pressure is used as the starting or reference point. If you want to know what the absolute pressure is, you must add the atmospheric pressure to the gauge reading. The following formula can be used: psia = psig + 14.7. This formula can be used as long as the gauge pressure is greater than or equal to 0 psig. For example, to convert a gauge reading of 50 psig to absolute pressure, you must add the atmospheric pressure of 14.696 psi to the gauge reading. Let us round off 14.696 to 15 for this example. Then 50 psig + 15 = 65 psia (pounds per square inch absolute), **Figure 1.23**. New generation gauges are of the digital variety, **Figure 1-24**. If the

Figure 1.22 The gauge on the left, called a *compound gauge*, reads pressures above and below atmospheric pressure. The gauge on the right, called the *high-pressure (high-side) gauge*, will read up to 500 psi. Photo by Eugene Silberstein

Figure 1.21 (A) Bourdon tube illustration. (B) A Bourdon tube. Photo by Eugene Silberstein



(A) (B)