

EIGHTH EDITION



**JOHN TOMCZYK
EUGENE SILBERSTEIN
BILL WHITMAN
BILL JOHNSON**

REFRIGERATION AND AIR CONDITIONING TECHNOLOGY

EIGHTH EDITION

REFRIGERATION AND AIR CONDITIONING TECHNOLOGY

JOHN A. TOMCZYK

EUGENE SILBERSTEIN

WILLIAM C. WHITMAN

WILLIAM M. JOHNSON



Australia • Brazil • Mexico • Singapore • United Kingdom • United States

This is an electronic version of the print textbook. Due to electronic rights restrictions, some third party content may be suppressed. Editorial review has deemed that any suppressed content does not materially affect the overall learning experience. The publisher reserves the right to remove content from this title at any time if subsequent rights restrictions require it. For valuable information on pricing, previous editions, changes to current editions, and alternate formats, please visit www.cengage.com/highered to search by ISBN#, author, title, or keyword for materials in your areas of interest.

Important Notice: Media content referenced within the product description or the product text may not be available in the eBook version.

**Refrigeration and Air Conditioning Technology,
Eighth Edition****John A. Tomczyk, Eugene Silberstein, William C.
Whitman, William M. Johnson**Vice President, GM Skills & Product Planning:
Dawn Gerrain

Product Team Manager: James DeVoe

Senior Director Development: Marah Bellegarde

Senior Product Development Manager: Larry Main

Senior Content Developer: John Fisher

Product Assistant: Jason Koumourdous

Vice President Marketing Services: Jennifer Ann Baker

Marketing Manager: Scott Chrysler

Senior Production Director: Wendy A. Troeger

Production Director: Andrew Crouth

Senior Content Project Manager: Kara A. DiCaterino

Senior Art Director: Jack Pendleton

Technology Project Manager: Joe Pliss

Cover Image: Biwa Studio/Stone/Getty Images

Interior Design Image: ©iStockphoto.com/simon2579

© 2017, 2003 Cengage Learning

WCN: 02-200-203

ALL RIGHTS RESERVED. No part of this work covered by the copyright herein may be reproduced or distributed in any form or by any means, except as permitted by U.S. copyright law, without the prior written permission of the copyright owner.

For product information and technology assistance, contact us at
Cengage Learning Customer & Sales Support, 1-800-354-9706For permission to use material from this text or product,
submit all requests online at www.cengage.com/permissions
Further permissions questions can be e-mailed to
permissionrequest@cengage.com

Library of Congress Control Number: 2015956456

ISBN: 978-1-305-57829-6

Cengage Learning20 Channel Center Street
Boston, MA 02210
USA

Cengage Learning is a leading provider of customized learning solutions with office locations around the globe, including Singapore, the United Kingdom, Australia, Mexico, Brazil, and Japan. Locate your local office at:

international.cengage.com/region

Cengage Learning products are represented in Canada by Nelson Education, Ltd.

To learn more about Cengage Learning, visit **www.cengage.com**Purchase any of our products at your local college store or at our preferred online store **www.cengagebrain.com****Notice to the Reader**

Publisher does not warrant or guarantee any of the products described herein or perform any independent analysis in connection with any of the product information contained herein. Publisher does not assume, and expressly disclaims, any obligation to obtain and include information other than that provided to it by the manufacturer. The reader is expressly warned to consider and adopt all safety precautions that might be indicated by the activities described herein and to avoid all potential hazards. By following the instructions contained herein, the reader willingly assumes all risks in connection with such instructions. The publisher makes no representations or warranties of any kind, including but not limited to, the warranties of fitness for particular purpose or merchantability, nor are any such representations implied with respect to the material set forth herein, and the publisher takes no responsibility with respect to such material. The publisher shall not be liable for any special, consequential, or exemplary damages resulting, in whole or part, from the readers' use of, or reliance upon, this material.

BRIEF CONTENTS

SECTION 1: Theory of Heat

Introduction	2
Unit 1 Heat, Temperature, and Pressure	16
Unit 2 Matter and Energy	30
Unit 3 Refrigeration and Refrigerants	39

SECTION 2: Safety, Tools and Equipment, and Shop Practices

Unit 4 General Safety Practices	86
Unit 5 Tools and Equipment	104
Unit 6 Fasteners	139
Unit 7 Tubing and Piping	155
Unit 8 Leak Detection, System Evacuation, and System Cleanup	187
Unit 9 Refrigerant and Oil Chemistry and Management—Recovery, Recycling, Reclaiming, and Retrofitting	223
Unit 10 System Charging	267
Unit 11 Calibrating Instruments	284

SECTION 3: Automatic Controls

Unit 12 Basic Electricity and Magnetism	296
Unit 13 Introduction to Automatic Controls	326
Unit 14 Automatic Control Components and Applications	339
Unit 15 Troubleshooting Basic Controls	370
Unit 16 Advanced Automatic Controls—Direct Digital Controls (DDCs) and Pneumatics	394

SECTION 4: Electric Motors

Unit 17 Types of Electric Motors	418
Unit 18 Application of Motors	450
Unit 19 Motor Controls	468
Unit 20 Troubleshooting Electric Motors	479

SECTION 5: Commercial Refrigeration

Unit 21 Evaporators and the Refrigeration System	498
Unit 22 Condensers	523
Unit 23 Compressors	558
Unit 24 Expansion Devices	594
Unit 25 Special Refrigeration System Components	621
Unit 26 Applications of Refrigeration Systems	668
Unit 27 Commercial Ice Machines	704
Unit 28 Special Refrigeration Applications	752

Unit 29 Troubleshooting and Typical Operating Conditions for Commercial Refrigeration	770
---	-----

SECTION 6: Air-Conditioning (Heating and Humidification)

Unit 30 Electric Heat	818
Unit 31 Gas Heat	836
Unit 32 Oil Heat	910
Unit 33 Hydronic Heat	969
Unit 34 Indoor Air Quality	1025

SECTION 7: Air-Conditioning (Cooling)

Unit 35 Comfort and Psychrometrics	1048
Unit 36 Refrigeration Applied to Air-Conditioning	1072
Unit 37 Air Distribution and Balance	1093
Unit 38 Installation	1143
Unit 39 Residential Energy Auditing	1167
Unit 40 Typical Operating Conditions	1218
Unit 41 Troubleshooting	1233

SECTION 8: All-Weather Systems

Unit 42 Heat Gains and Heat Losses in Structures	1266
Unit 43 Air Source Heat Pumps	1285
Unit 44 Geothermal Heat Pumps	1335

SECTION 9: Domestic Appliances

Unit 45 Domestic Refrigerators and Freezers	1372
Unit 46 Room Air Conditioners	1433

SECTION 10: Commercial Air-Conditioning and Chilled-Water Systems

Unit 47 High-Pressure, Low-Pressure, and Absorption Chilled-Water Systems	1464
Unit 48 Cooling Towers and Pumps	1509
Unit 49 Operation, Maintenance, and Troubleshooting of Chilled-Water Air-Conditioning Systems	1536
Unit 50 Commercial, Packaged Rooftop, Variable Refrigerant Flow, and Variable Air Volume Systems	1563

Appendix A Alternative Heating (Stoves and Fireplace Inserts)	1608
Appendix B Temperature Conversion Chart	1617

CONTENTS

Preface

Preface	xiii
New in This Edition	xiv
How to Use This Text and Supplementary Materials	xv
Support Materials	xviii
About the Authors	xx
Acknowledgments	xxi

SECTION 1: Theory of Heat

Introduction

Introduction	2
History of Refrigeration and Air-Conditioning (Cooling)	2
Green Awareness	6
History of Home and Commercial Heating	8
Career Opportunities	8
Technician Certification Programs	9
Programmatic Accreditation	10
National Skill Standards	11
Customer Relations and Technician Soft Skills	12

Unit 1 Heat, Temperature, and Pressure

Unit 1 Heat, Temperature, and Pressure	16
1.1 Heat, Temperature, and Pressure	16
1.2 Temperature	17
1.3 Introduction to Heat	18
1.4 Conduction	20
1.5 Convection	20
1.6 Radiation	21
1.7 Sensible Heat	22
1.8 Latent Heat	22
1.9 Specific Heat	24
1.10 Sizing Heating Equipment	24
1.11 Pressure	25
1.12 Atmospheric Pressure	26
1.13 Pressure Gauges	27

Unit 2 Matter and Energy

Unit 2 Matter and Energy	30
2.1 Matter	30
2.2 Mass and Weight	31
2.3 Density	31
2.4 Specific Gravity	31
2.5 Specific Volume	31
2.6 Gas Laws	32
2.7 Energy	34
2.8 Conservation of Energy	35
2.9 Energy Contained in Heat	35
2.10 Energy in Magnetism	35
2.11 Purchase of Energy	36
2.12 Energy Used as Work	36
2.13 Power	36
2.14 Electrical Power—the Watt	37

Unit 3 Refrigeration and Refrigerants

Unit 3 Refrigeration and Refrigerants	39
3.1 Introduction to Refrigeration	39
3.2 Refrigeration	40
3.3 Rating Refrigeration Equipment	40
3.4 The Refrigeration Process	41
3.5 Temperature and Pressure Relationship	43

3.6 Refrigeration Components	48
3.7 The Evaporator	48
3.8 The Compressor	50
3.9 The Condenser	52
3.10 The Refrigerant Metering Device	54
3.11 Matching Refrigeration Systems and Components	56
3.12 Refrigerants	58
3.13 Refrigerants Must Be Safe	60
3.14 Refrigerants Must Be Detectable	60
3.15 The Boiling Point of the Refrigerant	62
3.16 Pumping Characteristics	62
3.17 Popular Refrigerants and their Important Characteristics	62
3.18 Refrigerant Cylinder Color Codes	62
3.19 Recovery, Recycling, or Reclaiming of Refrigerants	65
3.20 Plotting the Refrigerant Cycle	65
3.21 Plotting the Refrigerant Cycle for Blends with Noticeable Temperature Glide (Zeotropic Blends)	79

SECTION 2: Safety, Tools and Equipment, and Shop Practices

Unit 4 General Safety Practices

Unit 4 General Safety Practices	86
4.1 Pressure Vessels and Piping	86
4.2 Electrical Hazards	90
4.3 Heat	95
4.4 Cold	96
4.5 Mechanical Equipment	96
4.6 Moving Heavy Objects	98
4.7 Refrigerants in Your Breathing Space	98
4.8 Using Chemicals	101

Unit 5 Tools and Equipment

Unit 5 Tools and Equipment	104
5.1 General Tools	104
5.2 Specialized Hand Tools	110
5.3 Tubing Tools	112
5.4 Specialized Service and Installation Equipment	117
5.5 Refrigerant Leak Detectors	120
5.6 Other Tools	122
5.7 Miscellaneous Tools and Equipment for Specialized Needs	131

Unit 6 Fasteners

Unit 6 Fasteners	139
6.1 Nails	139
6.2 Staples and Rivets	140
6.3 Threaded Fasteners	141
6.4 Concrete Fasteners	146
6.5 Other Fasteners	147

Unit 7 Tubing and Piping

Unit 7 Tubing and Piping	155
7.1 Purpose of Tubing and Piping	155
7.2 Types and Sizes of Tubing	155
7.3 Tubing Insulation	156
7.4 Line Sets	158

7.5	Cutting Tubing	158	10.7	Subcooling Charging Method for TXV Systems	277
7.6	Bending Tubing	159	10.8	Charging Near-Azeotropic (Zeotropic) Refrigerant Blends	279
7.7	Soldering and Brazing Processes	161	Unit 11 Calibrating Instruments 284		
7.8	Heat Sources for Soldering and Brazing	162	11.1	Calibration	284
7.9	Fluxing	168	11.2	Temperature-Measuring Instruments	284
7.10	Soldering Techniques	169	11.3	Pressure Test Instruments	288
7.11	Brazing Techniques	171	11.4	Electrical Test Instruments	289
7.12	Practical Soldering and Brazing Tips	172	11.5	Electronic Refrigerant Leak Detection Devices	291
7.13	Making Flare Joints	175	11.6	Flue-Gas Analysis Instruments	292
7.14	Swaging Techniques	176	11.7	General Maintenance	293
7.15	Compression Fittings	177	SECTION 3: Automatic Controls		
7.16	Steel and Wrought Iron Pipe	178	<hr/>		
7.17	Installing Steel Pipe	182	Unit 12 Basic Electricity and Magnetism 296		
7.18	Plastic Pipe	182	12.1	Atomic Structure	296
7.19	Alternative Mechanical Piping Connections	184	12.2	Movement of Electrons	297
Unit 8 Leak Detection, System Evacuation, and System Cleanup 187			12.3	Conductors	298
8.1	Leaks	187	12.4	Insulators	298
8.2	Basic Refrigerant Leak Detection	189	12.5	Electricity Produced from Magnetism	298
8.3	Advanced Leak Detection	191	12.6	Current	299
8.4	Standing Pressure Test	193	12.7	Units of Electrical Measurement	299
8.5	Leak Detection Tips	195	12.8	The Basic Electric Circuit	299
8.6	Repairing Leaks	198	12.9	Making Electrical Measurements	300
8.7	System Evacuation	199	12.10	Ohm's Law	300
8.8	General Evacuation Procedures	210	12.11	Characteristics of Series Circuits	304
8.9	Cleaning a Dirty System	218	12.12	Characteristics of Parallel Circuits	304
Unit 9 Refrigerant and Oil Chemistry and Management—Recovery, Recycling, Reclaiming, and Retrofitting 223			12.13	Electrical Power	305
9.1	Refrigerants and the Environment	223	12.14	Magnetism	305
9.2	Ozone Depletion	224	12.15	Inductance	306
9.3	Global Warming	225	12.16	Transformers	307
9.4	Refrigerants	226	12.17	Capacitance	308
9.5	CFC Refrigerants	227	12.18	Impedance	310
9.6	HCFC Refrigerants	227	12.19	Electrical Measuring Instruments	310
9.7	HFC Refrigerants	228	12.20	Sine Waves	314
9.8	Hydrofluoro-Olefin (HFO) Refrigerants	228	12.21	Wire Sizes	315
9.9	Hydrocarbon (HC) Refrigerants	229	12.22	Circuit Protection Devices	316
9.10	Naming Refrigerants	233	12.23	Semiconductors	319
9.11	Refrigerant Blends	234	Unit 13 Introduction to Automatic Controls 326		
9.12	Popular Refrigerants and Their Compatible Oils	235	13.1	Types of Automatic Controls	326
9.13	Refrigerant Oils and Their Applications	240	13.2	Devices that Respond to Thermal Change	326
9.14	Oil Groups	241	13.3	The Bimetal Device	328
9.15	Regulations	242	13.4	Control by Fluid Expansion	331
9.16	Recover, Recycle, or Reclaim	243	13.5	The Thermocouple	333
9.17	Methods of Recovery	245	13.6	Electronic Temperature-Sensing Devices	336
9.18	Mechanical Recovery Systems	248	Unit 14 Automatic Control Components and Applications 339		
9.19	Recovering Refrigerant from Small Appliances	255	14.1	Temperature Controls	339
9.20	Reclaiming Refrigerant	258	14.2	Low-Voltage Space Temperature Controls	341
9.21	Refrigerant Retrofitting	258	14.3	Line-Voltage Space Temperature Controls	345
9.22	Refrigerants and Tools in the Future	264	14.4	Sensing the Temperature of Solids	347
Unit 10 System Charging 267			14.5	Measuring the Temperature of Fluids	349
10.1	Charging a Refrigeration System	267	14.6	Pressure-Sensing Devices	352
10.2	Vapor Refrigerant Charging	267	14.7	Pressure Transducers	356
10.3	Liquid Refrigerant Charging	269	14.8	High-Pressure Controls	357
10.4	Weighing Refrigerant	272	14.9	Low-Pressure Controls	358
10.5	Using Charging Devices	273	14.10	Oil Pressure Safety Controls	359
10.6	Using Charging Charts	274			

14.11	Air Pressure Controls	361
14.12	Gas Pressure Switches	361
14.13	Switchless Devices That Control Fluid Flow	361
14.14	Water Pressure Regulators	362
14.15	Gas Pressure Regulators	363
14.16	Mechanical and Electromechanical Controls	363
14.17	Maintenance of Mechanical Controls	364
14.18	Maintenance of Electromechanical Controls	364
14.19	Service Technician Calls	365
Unit 15 Troubleshooting Basic Controls		370
15.1	Introduction to Troubleshooting	370
15.2	Troubleshooting a Simple Circuit	371
15.3	Troubleshooting a Complex Circuit	372
15.4	Troubleshooting the Thermostat	375
15.5	Troubleshooting Amperage in the Low-Voltage Circuit	377
15.6	Troubleshooting Voltage in the Low-Voltage Circuit	378
15.7	Troubleshooting Switches and Loads	378
15.8	Pictorial and Ladder Diagrams	385
15.9	Service Technician Calls	387
Unit 16 Advanced Automatic Controls—Direct Digital Controls (DDCs) and Pneumatics		394
16.1	Control Applications	394
16.2	Types of Control Systems	394
16.3	Pneumatic Controls	396
16.4	Cleaning and Drying Control Air	397
16.5	Control Components	398
16.6	Direct Digital Controls (DDCs)	403
16.7	Residential Electronic Controls	410
 SECTION 4: Electric Motors		
Unit 17 Types of Electric Motors		418
17.1	Uses of Electric Motors	418
17.2	Parts of an Electric Motor	418
17.3	Electric Motors and Magnetism	419
17.4	Determining a Motor's Speed	420
17.5	Start Windings	421
17.6	Starting and Running Characteristics	421
17.7	Electrical Power Supplies	422
17.8	Single-Phase Open Motors	424
17.9	Split-Phase Motors	424
17.10	The Centrifugal Switch	424
17.11	The Electronic Relay	426
17.12	Capacitor-Start Motors	426
17.13	Capacitor-Start, Capacitor-Run Motors	427
17.14	Permanent Split-Capacitor Motors	427
17.15	Shaded-Pole Motors	429
17.16	Three-Phase Motors	429
17.17	Single-Phase Hermetic Motors	431
17.18	The Potential Relay	432
17.19	Troubleshooting	434
17.20	The Current Relay	434
17.21	Positive Temperature Coefficient Resistor (PTCR)	435
17.22	Troubleshooting the PTCR	436
17.23	Two-Speed Compressor Motors	436
17.24	Special Application Motors	437
17.25	Three-Phase Compressor Motors	437
17.26	Variable-Speed Motors	438
17.27	DC Converters (Rectifiers)	441
17.28	Inverters and Variable Frequency Drives (VFDs)	443
17.29	Electronically Commutated Motors (ECMs)	446
17.30	Cooling Electric Motors	447
Unit 18 Application of Motors		450
18.1	Motor Applications	450
18.2	The Power Supply	450
18.3	Electric-Motor Working Conditions	457
18.4	Insulation Type or Class	458
18.5	Types of Bearings	458
18.6	Motor Mounting Characteristics	460
18.7	Motor Drives	462
Unit 19 Motor Controls		468
19.1	Introduction to Motor Control Devices	468
19.2	Full-Load and Locked-Rotor Amperage	469
19.3	The Relay	469
19.4	The Contactor	470
19.5	Motor Starters	472
19.6	Motor Protection	473
19.7	Inherent Motor Protection	474
19.8	External Motor Protection	474
19.9	National Electrical Code® Standards	476
19.10	Temperature-Sensing Devices	476
19.11	Magnetic Overload Devices	477
19.12	Restarting the Motor	477
Unit 20 Troubleshooting Electric Motors		479
20.1	Motor Troubleshooting	479
20.2	Mechanical Motor Problems	479
20.3	Removing Drive Assemblies	480
20.4	Belt Tension	481
20.5	Pulley Alignment	482
20.6	Electrical Problems	482
20.7	Open Windings	482
20.8	Shorted Motor Windings	484
20.9	Short Circuit to Ground (Frame)	485
20.10	Single-Phase Motor Starting Problems	488
20.11	Checking Capacitors	488
20.12	Identification of Capacitors	490
20.13	Wiring and Connectors	491
20.14	Troubleshooting Hermetic Motors	492
20.15	Service Technician Calls	492
 SECTION 5: Commercial Refrigeration		
Unit 21 Evaporators and the Refrigeration System		498
21.1	Refrigeration	498
21.2	Temperature Ranges of Refrigeration	499
21.3	The Evaporator	499
21.4	Boiling and Condensing	500
21.5	The Evaporator and Boiling Temperature	500
21.6	Removing Moisture	500
21.7	Heat Exchange Characteristics of the Evaporator	500
21.8	Types of Evaporators	503
21.9	Evaporator Evaluation	509
21.10	Latent Heat in the Evaporator	511
21.11	The Flooded Evaporator	511

21.12	Dry-Type Evaporator Performance	511	24.14	Example of a TXV Functioning with an Internal Equalizer	604
21.13	Evaporator Superheat	512	24.15	TXV Functioning with External Equalizers	605
21.14	Hot Pulldown (Excessively Loaded Evaporator)	512	24.16	TXV Response to Load Changes	609
21.15	Pressure Drop in Evaporators	513	24.17	Selection of TXV Valves	609
21.16	Liquid Cooling Evaporators (Chillers)	515	24.18	Balanced-Port TXV	609
21.17	Evaporators for Low-Temperature Applications	516	24.19	The Pressure-Limiting TXV	609
21.18	Defrost of Accumulated Moisture	517	24.20	Servicing the TXV	609
21.19	Evaporator and Defrost Efficiency Controller	518	24.21	Installing the Sensing Element	610
Unit 22	Condensers	523	24.22	Step-Motor Expansion Valves	611
22.1	The Condenser	523	24.23	Algorithms and PID Controllers	614
22.2	Water-Cooled Condensers	523	24.24	The Automatic Expansion Valve	615
22.3	Tube-Within-a-Tube Condensers	524	24.25	Automatic Expansion Valve Response to Load Changes	616
22.4	Mineral Deposits	524	24.26	Special Considerations for the TXV and AXV	616
22.5	Cleanable Tube-Within- a-Tube Condensers	526	24.27	The Capillary Tube Metering Device	617
22.6	Shell-and-Coil Condensers	527	24.28	Operating Charge for the Capillary Tube System	618
22.7	Shell-and-Tube Condensers	528	Unit 25	Special Refrigeration System Components	621
22.8	Wastewater Systems	528	25.1	The Four Basic Components	621
22.9	Refrigerant-to-Water Temperature Relationship for Wastewater Systems	531	25.2	Mechanical Controls	621
22.10	Recirculating Water Systems	533	25.3	Two-Temperature Controls	621
22.11	Cooling Towers	533	25.4	Evaporator Pressure Control	621
22.12	Natural-Draft Towers	533	25.5	Multiple Evaporators	624
22.13	Forced- or Induced-Draft Towers	534	25.6	Electric Evaporator Pressure-Regulating Valve	624
22.14	Evaporative Condensers	535	25.7	Crankcase Pressure Regulator	625
22.15	Air-Cooled Condensers	538	25.8	Adjusting the CPR Valve	627
22.16	High-Efficiency Condensers	541	25.9	Relief Valves	627
22.17	The Condenser and Low Ambient Conditions	542	25.10	Fan-Cycling Head Pressure Controls	628
22.18	Head Pressure Controls	544	25.11	Fan Speed Control for Controlling Head Pressure	629
22.19	Using the Condenser Superheat	554	25.12	Air Volume Control for Controlling Head Pressure	629
22.20	Heat Reclaim	554	25.13	Condenser Flooding and Condenser Splitting for Controlling Head Pressure	630
22.21	Floating Head Pressures	554	25.14	Electrical Controls	631
22.22	Service Technician Calls	555	25.15	Pressure Switches	633
Unit 23	Compressors	558	25.16	Low-Pressure Switch	633
23.1	The Function of the Compressor	558	25.17	Low-Pressure Control Applied as a Thermostat	633
23.2	Types of Compressors	560	25.18	Automatic Pumpdown Systems	635
23.3	Reciprocating Compressor Components	565	25.19	High-Pressure Control	639
23.4	Belt-Drive Mechanism Characteristics	575	25.20	Low-Ambient Fan Control	639
23.5	Direct-Drive Compressor Characteristics	576	25.21	Oil Pressure Safety Control	640
23.6	Reciprocating Compressor Efficiency	576	25.22	The Defrost Cycle	643
23.7	Discus Valve Design	578	25.23	Medium-Temperature Refrigeration	645
23.8	New Technology in Compressors	579	25.24	Random or Off-Cycle Defrost	645
23.9	Liquid in the Compressor Cylinder	588	25.25	Planned Defrost	645
23.10	System Maintenance and Compressor Efficiency	590	25.26	Low-Temperature Evaporator Defrost	645
Unit 24	Expansion Devices	594	25.27	Internal Heat Defrost (Hot Gas and Cool Gas Defrost)	646
24.1	Expansion Devices	594	25.28	External Heat Defrost	647
24.2	Thermostatic Expansion Valve	594	25.29	Defrost Termination and Fan Delay Control	648
24.3	TXV Components	596	25.30	Refrigeration Accessories	649
24.4	The Valve Body	597	25.31	Receivers	649
24.5	The Diaphragm	597	25.32	The King Valve on the Receiver	650
24.6	Needle and Seat	598	25.33	Filter Driers	650
24.7	The Spring	600	25.34	Refrigerant Check Valves	652
24.8	The Sensing Bulb and Transmission Tube	601	25.35	Refrigerant Sight Glasses	652
24.9	Types of Bulb Charge	601	25.36	Liquid Refrigerant Distributors	652
24.10	The Liquid Charge Bulb	601	25.37	Heat Exchangers	653
24.11	The Cross Liquid Charge Bulb	603	25.38	Suction-Line Accumulators	654
24.12	The Vapor (Gas) Charge Bulb	603			
24.13	The Cross Vapor Charge Bulb	604			

25.39	Suction-Line Filter Driers	656	Unit 29 Troubleshooting and Typical Operating Conditions for Commercial Refrigeration	770	
25.40	Suction Service Valves	657	29.1	Organized Troubleshooting	770
25.41	Discharge Service Valves	658	29.2	Troubleshooting High-Temperature Applications	771
25.42	Refrigeration Line Service Valves	658	29.3	Troubleshooting Medium-Temperature Applications	773
25.43	Diaphragm Valves	658	29.4	Troubleshooting Low-Temperature Applications	774
25.44	Ball Valves	658	29.5	Typical Air-Cooled Condenser Operating Conditions	774
25.45	Oil Separators	660	29.6	Calculating the Correct Head Pressure for Air-Cooled Equipment	775
25.46	Vibration Eliminators	661	29.7	Typical Operating Conditions for Water-Cooled Equipment	776
25.47	Pressure Access Ports	662	29.8	Typical Operating Conditions for Wastewater Condenser Systems	776
25.48	Crankcase Heat	663	29.9	Typical Operating Conditions for Recirculated Water Systems	776
25.49	Oil Pumps	664	29.10	Six Typical Problems	778
25.50	Compressor Oil Check Valve and Partition Wall	665	29.11	Low Refrigerant Charge	779
Unit 26 Applications of Refrigeration Systems			29.12	Refrigerant Overcharge	781
26.1	Application Decisions	668	29.13	Inefficient Evaporator	782
26.2	Reach-in Refrigeration	668	29.14	Inefficient Condenser	784
26.3	Self-Contained Reach-in Fixtures	669	29.15	Refrigerant Flow Restrictions	786
26.4	Individual Condensing Units	671	29.16	Inefficient Compressor	789
26.5	Single-Compressor Applications and Multiple Evaporators	672	29.17	Compressor Vacuum Test	790
26.6	Parallel Compressor Systems	675	29.18	Closed-Loop Compressor Running Bench Test	790
26.7	Secondary-Fluid Refrigeration Systems	683	29.19	Closed-Loop Compressor Running Field Test	792
26.8	Carbon Dioxide (R-744) Refrigeration Systems	685	29.20	Compressor Running Test in the System	792
26.9	Pressurized Liquid Systems	689	29.21	Diagnostic Chart for Commercial Refrigeration	794
26.10	Distributed Refrigeration Systems	691	29.22	Service Technician Calls	796
26.11	Evaporator Temperature Control	692	SECTION 6: Air-Conditioning (Heating and Humidification)		
26.12	Interconnecting Piping in Multiple-Evaporator Installations	692	<hr/>		
26.13	Fixture Temperature Control	693	Unit 30 Electric Heat	818	
26.14	The Evaporator and Merchandising	693	30.1	Introduction	818
26.15	Chest-Type Display Fixtures	694	30.2	Portable Electric Heating Devices	818
26.16	Refrigerated Shelves	695	30.3	Radiant Heating Panels	819
26.17	Closed Chest Fixtures	695	30.4	Electric Baseboard Heating	820
26.18	Controlling Sweating on Fixture Cabinets	696	30.5	Unit and Wall Heaters	820
26.19	Maintaining Store Ambient Conditions	696	30.6	Electric Hydronic Boilers	820
26.20	Walk-in Refrigeration	697	30.7	Central Forced-Air Electric Furnaces	821
26.21	Knock-Down Walk-in Coolers	697	30.8	Automatic Controls for Forced-Air Electric Furnaces	822
26.22	Evaporators in a Walk-in Cooler	698	30.9	The Low-Voltage Thermostat	822
26.23	Condensate Removal	698	30.10	Controlling Multiple Stages	824
26.24	Refrigeration Piping	699	30.11	Wiring Diagrams	824
26.25	Package Refrigeration for Walk-in Coolers	700	30.12	Control Circuits for Forced-Air Electric Furnaces	824
26.26	Refrigerated Air Driers	700	30.13	Blower Motor Circuits	826
Unit 27 Commercial Ice Machines			30.14	Contactors for Controlling Electric Furnaces	830
27.1	Packaged-Type Ice-Making Equipment	704	30.15	Airflow in Electric Furnaces	830
27.2	Making Flake Ice	704	30.16	Diagnostic Chart for Electric Heat	833
27.3	Making Cube Ice	713	30.17	Service Technician Calls	833
27.4	Microprocessors	730	Unit 31 Gas Heat		
27.5	Water and Ice Quality	735	31.1	Introduction to Gas-Fired, Forced-Hot-Air Furnaces	837
27.6	Package Ice Machine Location	742	<hr/>		
27.7	Troubleshooting Ice Makers	742			
27.8	Service Technician Calls	746			
Unit 28 Special Refrigeration Applications					
28.1	Special Refrigeration Applications	752			
28.2	Transport Refrigeration	752			
28.3	Truck Refrigeration Systems	752			
28.4	Railway Refrigeration	759			
28.5	Extra-Low-Temperature Refrigeration	760			
28.6	Cascade Systems	762			
28.7	Quick-Freezing Methods	762			
28.8	Marine Refrigeration	763			
28.9	Air Cargo Hauling	767			

36.16	The Condenser	1087	39.17	Flame Safeguard Controls	1202
36.17	Expansion Devices	1089	39.18	Excess Air	1204
36.18	Air-Side Components	1089	39.19	Venting	1204
36.19	Installation Procedures	1089	39.20	Draft	1207
Unit 37	Air Distribution and Balance	1093	39.21	High-Efficiency Gas Furnace Anatomy	1209
37.1	Conditioning Equipment	1093	39.22	HVAC/R System Testing	1211
37.2	Correct Air Quantity	1094	39.23	Numerical Analysis and Reporting	1212
37.3	The Forced-Air System	1094	Unit 40	Typical Operating Conditions	1218
37.4	The Blower	1094	40.1	Mechanical Operating Conditions	1218
37.5	System Pressures	1097	40.2	Relative Humidity and the Load	1218
37.6	Air-Measuring Instruments for Duct Systems	1098	40.3	Relationships of System Component Under Load Changes	1219
37.7	Types of Fans and Blowers	1099	40.4	Evaporator Operating Conditions	1219
37.8	Types of Drive Assemblies	1102	40.5	High Evaporator Load and a Cool Condenser	1219
37.9	The Supply Duct System	1103	40.6	Grades of Equipment	1222
37.10	Duct System Standards	1107	40.7	Documentation with the Unit	1223
37.11	Duct Materials	1107	40.8	Establishing a Reference Point on Unknown Equipment	1224
37.12	Duct Air Movement	1117	40.9	System Pressures and Temperatures for Different Operating Conditions	1225
37.13	Balancing Dampers	1118	40.10	Equipment Efficiency Rating	1228
37.14	Zoning	1119	40.11	Typical Electrical Operating Conditions	1229
37.15	Duct Insulation	1122	40.12	Matching the Unit to the Correct Power Supply	1229
37.16	Blending the Conditioned Air with Room Air	1123	40.13	Starting the Equipment with the Correct Data	1229
37.17	The Return-Air Duct System	1124	40.14	Finding a Point of Reference for an Unknown Motor Rating	1229
37.18	Sizing Duct for Moving Air	1124	40.15	Determining the Compressor Running Amperage	1230
37.19	Measuring Air Movement for Balancing	1128	40.16	Compressors Operating at Full-Load Current	1230
37.20	The Air Friction Chart	1130	40.17	High Voltage, the Compressor, and Current Draw	1230
37.21	Practical Troubleshooting Techniques	1138	40.18	Current Draw and the Two-Speed Compressor	1231
Unit 38	Installation	1143	Unit 41	Troubleshooting	1233
38.1	Introduction to Equipment Installation	1143	41.1	Introduction	1233
38.2	Installing Square and Rectangular Duct	1143	41.2	Mechanical Troubleshooting	1233
38.3	Installing Round Metal Duct Systems	1145	41.3	Approach Temperature and Temperature Difference	1237
38.4	Insulation and Acoustical Lining for Metal Duct	1146	41.4	Gauge Manifold Usage	1238
38.5	Installing Ductboard Systems	1146	41.5	When to Connect the Gauges	1239
38.6	Installing Flexible Duct	1148	41.6	Low-Side Gauge Readings	1240
38.7	Electrical Installation	1148	41.7	High-Side Gauge Readings	1240
38.8	Installing the Refrigeration System	1150	41.8	Temperature Readings	1242
38.9	Installing Split-System Air Conditioners	1154	41.9	Charging Procedures in the Field	1247
38.10	The Split-System Condensing Unit	1158	41.10	Electrical Troubleshooting	1250
38.11	Installing Refrigerant Piping on Split-Systems	1159	41.11	Compressor Overload Problems	1251
38.12	Equipment Start-Up	1163	41.12	Compressor Electrical Checkup	1252
Unit 39	Residential Energy Auditing	1167	41.13	Troubleshooting the Circuit Electrical Protectors—Fuses and Breakers	1256
39.1	Introduction	1167	41.14	Diagnostic Chart for Air-Conditioning (Cooling) Systems	1257
39.2	Residential (Home) Energy Auditing	1168	41.15	Service Technician Calls	1258
39.3	Performing a Home Energy Audit	1169	SECTION 8: All-Weather Systems		
39.4	Diagnostic Testing	1175	Unit 42	Heat Gains and Heat Losses in Structures	1266
39.5	Blower Door Testing	1175	42.1	Introduction to Heat Gain and Heat Loss	1266
39.6	Infrared Scanning Using a Thermal Imaging Camera	1178			
39.7	Sealing Air Leaks	1185			
39.8	Duct Leakage Testing	1188			
39.9	Duct Pressurization Test for Total Air Leakage	1193			
39.10	Duct Leakage to the Outdoors	1194			
39.11	Combustion Efficiency and Safety Testing	1194			
39.12	Furnace Efficiency Testing	1197			
39.13	Furnace Efficiency Ratings	1199			
39.14	Flame Color	1199			
39.15	Furnace Preventive Maintenance	1200			
39.16	Spillage and Backdrafting	1201			

42.2	Methods to Determine the Heat Gain and Heat Loss of a Structure	1267
42.3	Indoor and Outdoor Design Conditions for Heating and Cooling	1268
42.4	U-Values and R-Values	1269
42.5	Introduction to Heat Gain and Heat Loss Calculations	1271
42.6	Elements of Structural Heat Loss (Heating Mode)	1271
42.7	Elements of Structural Heat Gain (Cooling Mode)	1278
Unit 43	Air Source Heat Pumps	1285
43.1	Reverse-Cycle Refrigeration	1285
43.2	Heat Sources for Winter	1286
43.3	The Four-Way Reversing Valve	1287
43.4	The Air-to-Air Heat Pump	1290
43.5	Refrigerant Line Identification	1290
43.6	Metering Devices	1292
43.7	Thermostatic Expansion Valves	1292
43.8	The Capillary Tube	1294
43.9	Combinations of Metering Devices	1295
43.10	Electronic Expansion Valves	1296
43.11	Orifice Metering Devices	1296
43.12	Liquid-Line Accessories	1296
43.13	Application of the Air-to-Air Heat Pump	1298
43.14	Auxiliary Heat	1298
43.15	Balance Point	1299
43.16	Coefficient of Performance	1299
43.17	The Split-Type, Air-to-Air Heat Pump	1300
43.18	The Indoor Unit	1300
43.19	Temperature of the Conditioned Air	1301
43.20	The Outdoor Unit	1302
43.21	Package Air-to-Air Heat Pumps	1303
43.22	Controls for the Air-to-Air Heat Pump	1304
43.23	The Defrost Cycle	1311
43.24	Indoor Fan Motor Control	1314
43.25	Second-Stage Electric Heat	1314
43.26	Servicing the Air-to-Air Heat Pump	1316
43.27	Troubleshooting the Electrical System	1316
43.28	Troubleshooting Mechanical Problems	1317
43.29	Troubleshooting the Four-Way Reversing Valve	1318
43.30	Troubleshooting the Compressor	1320
43.31	Checking the Charge	1321
43.32	Special Applications for Heat Pumps	1321
43.33	Heat Pumps using Scroll Compressors	1322
43.34	Heat Pump Systems with Variable-Speed Motors	1323
43.35	Diagnostic Chart for Heat Pumps in the Heating Mode	1325
43.36	Service Technician Calls	1325
Unit 44	Geothermal Heat Pumps	1335
44.1	Reverse-Cycle Refrigeration	1335
44.2	Geothermal Heat Pump Classifications	1335
44.3	Open-Loop Systems	1336
44.4	Water Quality	1337
44.5	Closed-Loop Systems	1338
44.6	Ground-Loop Configurations and Flows	1342
44.7	System Materials and Heat Exchange Fluids	1345
44.8	Geothermal Wells and Water Sources for Open-Loop Systems	1347

44.9	Water-to-Water Heat Pumps	1349
44.10	Troubleshooting	1352
44.11	Direct Geothermal Heat Pump Systems	1354
44.12	Service Technician Calls	1365

SECTION 9: Domestic Appliances

Unit 45 Domestic Refrigerators and Freezers 1372

45.1	Refrigeration	1372
45.2	Capacity of Domestic Systems	1380
45.3	The Evaporator	1381
45.4	The Compressor	1384
45.5	The Condenser	1386
45.6	Metering Device	1390
45.7	Typical Operating Conditions	1392
45.8	Ice-Maker Operation	1394
45.9	Wiring and Controls	1395
45.10	Servicing the Appliance	1404
45.11	Service Technician Calls	1419

Unit 46 Room Air Conditioners 1433

46.1	Air-Conditioning and Heating with Room Units	1433
46.2	Room Air-Conditioning—Cooling	1434
46.3	The Refrigeration Cycle—Cooling	1435
46.4	Heat-Pump-Style Room Units	1437
46.5	Installation	1440
46.6	Controls for Cooling-Only Room Units	1447
46.7	Controls in Cooling and Heating Units	1450
46.8	Maintaining and Servicing Room Units	1450
46.9	Service Technician Calls	1457

SECTION 10: Commercial Air-Conditioning and Chilled-Water Systems

Unit 47 High-Pressure, Low-Pressure, and Absorption Chilled-Water Systems 1464

47.1	Chillers	1465
47.2	Compression Cycle in High-Pressure Chillers	1466
47.3	Reciprocating Compressors in High-Pressure Chillers	1466
47.4	Scroll Compressors in High-Pressure Chillers	1468
47.5	Rotary Screw Compressors in High-Pressure Chillers	1469
47.6	Centrifugal Compressors in High-Pressure Chillers	1470
47.7	Evaporators for High-Pressure Chillers	1474
47.8	Condensers for High-Pressure Chillers	1478
47.9	Metering Devices for High-Pressure Chillers	1481
47.10	Low-Pressure Chillers	1484
47.11	Compressors for Low-Pressure Chillers	1484
47.12	Condensers for Low-Pressure Chillers	1487
47.13	Metering Devices for Low-Pressure Chillers	1487
47.14	Purge Units	1487
47.15	Absorption Air-Conditioning Chillers	1488
47.16	Motors and Drives for Chillers	1498

Unit 48 Cooling Towers and Pumps	1509		
48.1 Cooling Tower Function	1509		
48.2 Types of Cooling Towers	1511		
48.3 Fire Protection	1514		
48.4 Fill Material	1515		
48.5 Flow Patterns	1515		
48.6 Tower Materials	1516		
48.7 Fan Section	1517		
48.8 Tower Access	1518		
48.9 Tower Sump	1518		
48.10 Makeup Water	1519		
48.11 Blowdown	1520		
48.12 Balancing the Water Flow in a Cooling Tower	1522		
48.13 Water Pumps	1522		
48.14 Chemical-Free Treatment of Cooling Tower Water	1530		
Unit 49 Operation, Maintenance, and Troubleshooting of Chilled-Water Air-Conditioning Systems	1536		
49.1 Chiller Start-Up	1536		
49.2 Valves for Large Systems	1542		
49.3 Scroll and Reciprocating Chiller Operation	1545		
49.4 Large Positive-Displacement Chiller Operation	1546		
49.5 Centrifugal Chiller Operation	1546		
49.6 Air-Cooled Chiller Maintenance	1546		
49.7 Water-Cooled Chiller Maintenance	1548		
49.8 Absorption Chilled-Water System Start-Up	1551		
49.9 Absorption Chiller Operation and Maintenance	1552		
49.10 General Maintenance for all Chillers	1553		
49.11 Low-Pressure Chillers	1553		
49.12 High-Pressure Chillers	1555		
49.13 Refrigerant Safety	1555		
49.14 Service Technician Calls	1555		
Unit 50 Commercial, Packaged Rooftop, Variable Refrigerant Flow, and Variable Air Volume Systems	1563		
50.1 Rooftop Package Units	1564		
50.2 Installation of Packaged Rooftop Units	1565		
50.3 Economizers	1571		
50.4 Economizer Modes of Operation	1576		
50.5 Ashrae Standard 62	1578		
50.6 Demand Control Ventilation (DCV)	1579		
50.7 Traditional Constant-Volume Air Distribution Methods	1580		
50.8 Variable Air Volume (VAV) Systems	1580		
50.9 Blowers on VAV Systems	1580		
50.10 VAV Boxes and Terminal Units	1581		
50.11 Hot Water in the Reheat Coils	1583		
50.12 Chilled-Water VAV Systems	1584		
50.13 Variable Refrigerant Flow (VRF) Systems	1589		
50.14 Dry Coolers	1602		
Appendix A Alternative Heating (Stoves and Fireplace Inserts)	1608		
A.1 Wood-Burning Stoves	1608		
A.2 Organic Makeup and Characteristics of Wood	1608		
A.3 Environmental Protection Agency (EPA) Regulations	1609		
A.4 Creosote	1609		
A.5 Design Characteristics of Wood-Burning Stoves	1609		
A.6 Installation Procedures	1613		
A.7 Smoke Detectors	1614		
A.8 Gas Stoves	1615		
A.9 Fireplace Inserts	1615		
Appendix B Temperature Conversion Chart	1617		
Glossary/Glosario	1619		
Index	1671		

PREFACE

R*efrigeration & 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 HVAC/R 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 HVAC/R technician certification and home-study examinations.

The book is also written to correspond to the National Skill Standards for HVAC/R 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. At the time of this writing, every central split cooling system manufactured in the United States today 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. SEER is calculated on the basis of the total amount of cooling (in Btus) the system will provide over the entire season, divided by the total number watt-hours it will consume. Higher SEER ratings reflect a more efficient cooling system. Air-conditioning and refrigeration technicians are responsible for following procedures to protect our environment, particularly with regard to the handling of refrigerants. Technician certification has become increasingly important in the industry.

Global warming has become a major environmental issue. When HVAC/R 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 HVAC/R 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 HVAC/R technicians to meet the needs of more sophisticated, energy-efficient buildings and HVAC/R 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 most 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. A technical review takes place before a revision is started and also during the revision process.

Illustrations and photos are used extensively throughout the text. Full-color treatment of most 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. Difficult decisions had to be made to provide text in a format that would meet the needs of varied institutions. Instructors from different areas of the country and from various institutions were asked for their ideas regarding the organization of the instructional content.

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 IN THIS EDITION

NEW AND/OR EXPANDED CONTENT HAS BEEN ADDED TO THE TEXT IN THE FOLLOWING AREAS:

- WiFi and learning thermostats
- Thermostat applications for smart phones and other electronic hand-held devices
- Fossil-fuel furnace technologies
- Intelligent refrigeration case controllers
- Variable air volume (VAV)
- Variable refrigerant flow (VRF)
- Ultraviolet germicidal irradiation
- Natural refrigerants (hydrocarbons), their structure, boiling points, GWP, ODP, applications, charge amounts, serviceability, handling, transportation and safety
- R-22 alternatives
- System efficiencies with respect to EER, SEER, HSPF
- Supermarket refrigeration systems
- Microchannel heat exchangers
- Air-conditioning and heat pump technologies
- Ductless split systems
- Variable frequency drives
- Dry coolers
- Mechanical piping techniques
- Basic electronic theory
- Biofuels
- Blueflame burners
- Boiler setback controls
- Mixed air systems
- Psychrometrics
- Ventilation requirements
- Detailed coverage on crankcase heaters
- Detailed coverage on compressor oil pumps, partition walls, and oil check valves
- New photos on scroll compressor valve plates and other damaged valve plates
- Hydrofluoro-olefin (HFO) refrigerants
- Digital evaporator defrost and efficiency controllers
- Digital “Smart” gauges and manifolds including Bluetooth technologies
- Calculating water usage for water-cooled condensers

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 lecture outline provided in the *Instructor's Manual* may be utilized in this process. Lab assignments may be made at this time, followed by the students completing the lab review questions.

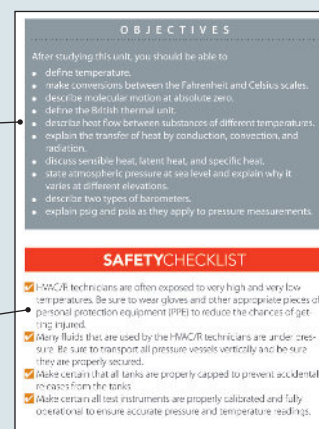
The instructor resource DVD may be used to access a computerized test bank for end-of-unit review questions, teaching tips, PowerPoint® presentations, and more.



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.



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.

R-22 boils at about -41°F . **AR** Do not perform the following exercises—allowing refrigerant to intentionally escape into the atmosphere is against the law! We mention these examples here for illustration purposes only. **AR**

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."

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 (for example, lowering energy costs, reducing operating and maintenance costs, increasing productivity, and decreasing the amount of pollution generated) are highlighted in green throughout the text.

The correct size, layout, and installation of tubing, piping, and fittings helps to keep a refrigeration or air-conditioning system operating properly and efficiently and prevents refrigerant loss.

HVAC 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 pattern.
- 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

HVAC 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.

PREVENTIVE MAINTENANCE FOR REFRIGERATION

PACKAGED EQUIPMENT. Packaged equipment is built and designed for minimum maintenance because the owner may be the person that takes care of it until a breakdown occurs. Most of the fan motors are permanently lubricated and will run until they quit, at which time they are replaced with new ones.

The owners should be educated to keep the condensers clean and not to stack inventory so close as to block the condenser airflow. When the unit is a reach-in cooler, the owner should be cautioned to follow the manufacturer's directions in loading the box. The load line on the inside should be observed for proper air distribution.

inspected and cleaned regularly. The technician cannot always tell when a coil is dirty by looking at the evaporator. Grease or dirt may be in the core of the coil. Routine cleaning of the evaporator once a year will usually keep the coil clean. **SAFETY PRECAUTION:** Use only approved cleaning compounds where food is present. Turn off the power before cleaning any system. Cover the fan motors and all electrical connections when cleaning to prevent water and detergent from getting into them.

The motors in the evaporator unit are usually sealed and permanently lubricated. If not, they should be lubricated at recommended intervals, which are often marked on the motor. Observe the fan blade for alignment and look for bearing

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.

Diagnostic Charts

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

Problem	Possible Cause	Possible Repair
No heat—thermostat calling for heat	Open disconnect switch Open fuse or breaker High-temperature fuse link open circuit Faulty high-voltage wiring or connections Control-voltage power supply off	Close disconnect switch. Replace fuse or reset breaker and determine why it opened. Tighten loose connection at fuse link causing heat. Repair or replace faulty wiring or connections. Check control-voltage fuses and safety devices.
Insufficient heat	Faulty control-voltage wiring or connections Heating element burned, open circuit	Repair or replace faulty wiring or connections. Replace heating element—check airflow.
	Portion of heaters or limits open circuit Low voltage	See above. Correct voltage.

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 14.66.*

The technician arrives at the motel, parking alongside the building so as not to block the front door or the motel's registration parking areas. When the property manager comes into the office to greet the technician, the technician intro-

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.

SUMMARY

- Thermometers measure temperature. Four temperature scales are Fahrenheit, Celsius, Fahrenheit absolute (Rankine), and Celsius absolute (Kelvin).
- Molecules in matter are constantly moving. The higher the temperature, the faster they move.
- The British thermal unit (Btu) describes the quantity of heat in a substance. One Btu is the amount of heat necessary to raise the temperature of 1 lb of water 1°F.
- The transfer of heat by conduction is the transfer of heat from molecule to molecule.
- The transfer of heat by convection is the actual moving of heat in a fluid (vapor state or liquid state) from one place to another.
- Radiant heat is a form of energy that does not depend on matter as a medium of transfer. Solid objects absorb the energy, become heated, and transfer the heat to the air.
- Sensible heat causes a rise in temperature of a substance.
- Latent (or hidden) heat is heat added to a substance that causes a change of state and does not register on a thermometer.
- Specific heat is the amount of heat (measured in Btu) required to raise the temperature of 1 lb of a substance 1°F. Substances have different specific heats.
- Pressure is the force applied to a specific unit of area. The atmosphere around the earth has weight and therefore exerts pressure.
- Barometers measure atmospheric pressures in inches of mercury. Two of the barometers used are the mercury and the aneroid.
- Gauges have been developed to measure pressures in enclosed systems. Two common gauges used in the air-conditioning, heating, and refrigeration industry are the compound gauge and the high-pressure gauge.

REVIEW QUESTIONS

1. Temperature is defined as
 - A. how hot it is.
 - B. the level of heat.
 - C. how cold it is.
 - D. why it is hot.
2. State the standard conditions for water to boil at 212°F.
3. List four types of temperature scales.
4. Under standard conditions, water freezes at ____ °C.
5. Molecular motion stops at ____ °F.

Summary

The Summary appears at the end of each unit prior to the Review Questions. It can be used to review the unit and to stimulate class discussion.

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

INSTRUCTOR'S MANUAL

This manual includes an overview of each text unit, including a summary description, a list of objectives, and important safety notes. The manual provides diagnoses for service technician calls that are not solved in the text. It also includes references to lab exercises associated with each unit. “Special Notes to Instructors” specify how to create an equipment “problem” for students to resolve during certain lab exercises. The manual also provides answers to the review questions in the text and to all questions in the *Lab Manual and Workbook* (review and lab exercises). ISBN: 978-1-305-58326-9.

LAB MANUAL AND WORKBOOK

The *Lab Manual and Workbook* includes a unit overview, key terms, and a unit review test. Each lab provides a general introduction to the lab, including objectives, text references, tools, materials, and safety precautions. The manual then provides a series of practical exercises for the student to complete in a “hands-on” lab environment, including maintenance instructions for the workstation and tools. Cross references to the “Special Notes to Instructors” in the *Instructor's Manual* allow the instructor to create a system “problem” to be solved in the lab. ISBN: 978-1-305-57870-8

INSTRUCTOR RESOURCES DVD

This educational resource creates a truly electronic classroom. It is a DVD containing tools and instructional resources that enrich the classroom and make the instructor's preparation time shorter. The elements of the instructor resource link directly to the text to provide a unified instructional system. With the instructor resource the instructor can spend time teaching, not preparing to teach. ISBN: 978-1-305-58327-6.

Features contained in the instructor resource include the following:

- Syllabus. This is the standard course syllabus for this textbook, providing a summary outline for teaching HVAC/R.
- Teaching Tips. Teaching hints form a basis for presenting concepts and material. Key points and concepts can be highlighted graphically to enhance student retention.
- Lecture Outlines. The key topics and concepts that should be covered for each unit are outlined.
- 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 true/false, multiple-choice, fill-in-the-blank, 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 Learning solutions
- create multiple test versions in an instant
- deliver tests from your LMS, your classroom, or wherever you want

Contact Cengage Learning 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

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 sand-box 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 HVAC equipment that follows. It also challenges learners to master diagnostic and troubleshooting skills across seven pieces of HVAC 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: HVAC 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



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.

Professor Tomczyk has worked in refrigeration, heating, and air-conditioning service and project engineering and served as a technical writing consultant in both the academic and industrial fields. His technical articles have been featured in the *Refrigeration News*, *Service and Contracting Journal*, and *Engineered Systems Journal*. He writes monthly for the *Air Conditioning, Heating, Refrigeration News* and is coauthor of an EPA-approved *Technician Certification Program Manual* and a Universal R-410A Safety and Retrofitting Training Manual. Professor Tomczyk also is the author of the book *Troubleshooting and Servicing Modern Air Conditioning and Refrigeration Systems*, published by ESCO Press. He also is co-owner of Delta Tee Solutions Inc., a Subchapter-S Corporation and sole owner of Technical Writing Services, LLC. Professor Tomczyk has recently retired from his professorship at Ferris State University after 29 years of service with the title of Professor Emeritus. While continuing consulting through his two companies and being a member of many HVAC/R trade organizations, he will be spending his winters in Maui, Hawaii and the remainder of the year living in the quaint beach town of Empire located in the Sleeping Bear National Lakeshore in Michigan.



EUGENE SILBERSTEIN

Over the past 30-plus years, Eugene has been involved in all aspects of the HVAC/R industry from field technician and system designer to company owner, teacher, administrator, consultant, and author. Eugene is presently an Assistant Professor and the lead faculty member in the HVAC/R program at Suffolk County Community College in Brentwood, New York. Eugene has over 20 years of teaching experience and has taught at a number of institutions in the Greater New York area.

Eugene earned his dual Bachelors Degree from The City College of New York and his Masters of Science degree from Stony Brook University, where he specialized in Energy and Environmental Systems, studying renewable and sustainable energy sources such as wind, solar, geothermal, biomass, and hydropower. He presently holds the Certified Master HVAC/R Educator (CMHE) credential from the ESCO Group and the Building Energy Assessment Professional (BEAP) credential issued by ASHRAE.

As an active member of both ASHRAE and RSES, Eugene served as the subject matter expert and wrote the production scripts for over 30 education videos directly relating to our industry. Other book credits include *Residential Construction Academy: HVAC*, 1st and 2nd Edition, *Pressure Enthalpy Without Tears* (2006), *Heat Pumps*, 1st and 2nd Edition, and *Psychrometrics Without Tears* (2014). Eugene has also written a number of articles for industry newspapers and magazines.

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

BILL WHITMAN

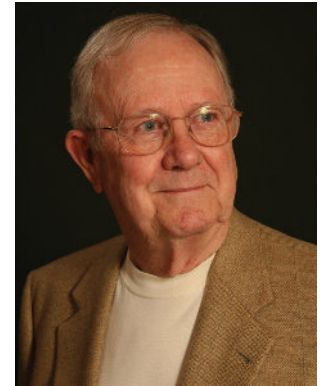
Bill Whitman graduated from Keene State College in Keene, New Hampshire, with a bachelor's degree in industrial education. He received his master's degree in school administration from St. Michael's College in Winooski, Vermont.



After instructing drafting courses for 3 years, Mr. Whitman became the Director of Vocational Education for the Burlington Public Schools in Burlington, Vermont, a position he held for 8 years. He spent 5 years as the Associate Director of Trident Technical College in Charleston, South Carolina. Mr. Whitman was the head of the Department of Industry for Central Piedmont Community College in Charlotte, North Carolina, for 18 years.

BILL JOHNSON

Bill Johnson graduated from Southern Polytechnic with an associate's degree in gas fuel technology and refrigeration. He worked for the North Carolina's Weights and Measures Department; Coosa Valley Vocational and Technical Institute in Rome, Georgia; and the Trane Company of North Carolina. He also owned and operated an air-conditioning, heating, and refrigeration business for 10 years. He has unlimited North Carolina licenses in heating, air-conditioning, and refrigeration. Mr. Johnson taught heating, air-conditioning, and refrigeration installation, service, and design for 15 years at Central Piedmont Community College in Charlotte, North Carolina, and was instrumental in standardizing the heating, air-conditioning, and refrigeration curriculum for the state community college system. He has written a series of articles for the website of the *Air Conditioning, Heating, Refrigeration News*. These articles, called "BTU Buddy," describe service situation calls for technicians. Mr. Johnson has also authored the *BTU Buddy Notebook* along with two textbooks, *Practical Heating Technology* and *Practical Cooling Technology*, published by Cengage Learning.



ACKNOWLEDGMENTS

The authors thank the following individuals, companies, and universities for their valuable contributions to this text:

James DeVoe, Senior Acquisitions Editor, for his work with the authors and the publisher to produce a workable text that is both economical and comprehensive. His perpetual energies and insistence on the best possible product have resulted in a quality text that is usable both in schools and in the field.

John Fisher, Senior Product Manager, for his work with the authors and publisher to ensure the accuracy of the details in this text. His professional, thorough, and enthusiastic handling of the text manuscript will provide the student with a well-presented, usable product.

Kara DiCaterino, Senior Content Project Manager, for a great job of making sure all pages, artwork, and photographs are well presented and easy to follow. Her professional skills and talents are greatly appreciated.

The late **Ed Bottum, Sr.**, President of Refrigeration Research, Inc., in Brighton, Michigan, for supplying much of the history and many photographs for the timeline found in the introduction to this text. Mr. Bottum's historical collection of refrigeration items and artifacts in Brighton, Michigan, has been designated a National Historic Site by the American Society of Mechanical Engineers (ASME).

Ferris State University, Big Rapids, Michigan, for permission to use their building and HVAC/R applications laboratories to take digital photographs. These digital photographs have certainly enhanced many units in this book.

Bill Litchy, Training Materials Manager, Scotsman Ice Systems, for his valued technical consultation and professional guidance in Unit 27, "Commercial Ice Machines," in this edition. Technical literature, photographs, and illustrations from the Scotsman Company have greatly enhanced this book.

Danny Moore, Director of Technical Support, Hoshizaki America, Inc., for his technical assistance in Unit 27, "Commercial Ice Machines." His published technical articles on the topics of water and ice quality and water filtration and treatment surely enhanced the quality of this unit.

Mitch Rens, Service Publications Manager, Manitowoc Ice Inc., for his valued technical assistance and professional consultation in Unit 27, "Commercial Ice Machines." Technical literature and photographs from Manitowoc have made the unit current and applicable.

Rex Ambbs, Manager of GeoFurnace Heating and Cooling, LLC, and CoEnergies, LLC, in Traverse City, Michigan, for his assistance with the enhancements to Unit 44, "Geothermal Heat Pumps." He supplied detailed technical information and digital photographs on waterless, earth-coupled, closed-loop geothermal heat pump technology.

Jim Holstine, Manager of GeoFurnace Heating and Cooling, LLC, and CoEnergies, LLC, in Traverse City, Michigan, for his technical assistance in Unit 44, "Geothermal Heat Pumps."

Dennis Weston and **Tom Kiessel**, Managers of CoEnergies, LLC, in Traverse City, Michigan, for supplying many digital photographs of waterless, earth-coupled, closed-loop geothermal heat pump systems used in Unit 44, "Geothermal Heat Pumps."

Roger McDow, Senior Instructional Lab Facilitator, Central Piedmont Community College in Charlotte, North Carolina, for assisting in the setup of the photographic sessions for all editions of this book. He organized and provided many tools and controls for photography that have provided an invaluable educational experience for students.

Tony Young, Emerson Climate Technologies, Inc., for making his company's valuable technical literature and photographs available for use in this edition.

Modine Manufacturing Company, 1500 DeKoven Ave., Racine, Wisconsin, 53403, for the use of both its technical literature and photographs of the all-aluminum Micro Channel coil technology.

Dan Mason, Danfoss Turbocore Compressors, Inc., for making his company's technical literature and photographs available for use in this edition.

Sporlan Division, Parker Hannifin Corporation, for making its technical literature and photographs available for use in this edition.

John Levey of Oilheat Associates, Inc., in Wantagh, New York, for his assistance in compiling and reviewing material for Unit 32, "Oil Heat," as well as providing new images for use in the text.

A special thanks to the family members and close relatives of the authors for their help and patience while this edition was being developed.

The contributions of the following reviewers of the fourth, fifth, and sixth edition texts are gratefully acknowledged:

George Gardianos, Lincoln Technical Institute, Mahwah, New Jersey
Raymond Norris, Central Missouri State University, Warrensburg, Missouri

Arthur Gibson, Erwin Technical Center, Tampa, Florida

Robert J. Honer, New England Institute of Technology at Palm Beach, West Palm Beach, Florida

Richard McDonald, Santa Fe Community College, Gainesville, Florida

Joe Moravek, Lee College, Baytown, Texas

Neal Broyles, Rolla Technical Institute, Rolla, Missouri

John B. Craig, Sheridan Vocational Technical Center, Hollywood, Florida

Rudy Hawkins, Kentucky Tech–Jefferson Campus, Louisville, Kentucky

Richard Dorssom, N.S. Hillyard AVTS, St. Joseph, Missouri

Robert Ortero, School of Cooperative Technical Education, New York, New York

John Sassen, Ranken Technical College, St. Louis, Missouri

Billy W. Truitt, Worcester Career and Technology Center, Newark, Maryland

George M. Cote, Erwin Technical Center

Marvin Maziarz, Niagara County Community College, Sanborn, New York

Greg Skudlarek, Minneapolis Community and Technical College, Minneapolis, Minnesota

Chris Rebecki, Baran Institute, Windsor and West Haven, Connecticut

Wayne Young, Midland College, Midland, Texas

Darren M. Jones, Meade County Area Technology Center, Brandenburg, Kentucky

Keith Fuhrman, Del Mar College West, Corpus Christi, Texas

Eugene Dickson, Indian River Community College, Fort Pierce, Florida

Mark Davis, New Castle School of Trades, Pulaski, Pennsylvania

Phil Coulter, Durham College, Skills Training Center (Whitby Campus), Whitby, Ontario, Canada

Larry W. Wyatt, Advanced Tech Institute, Virginia Beach, Virginia

Bob Kish, Belmont Technical College, St. Clairsville, Ohio

John Pendleton, Central Texas College, Killeen, Texas

Richard Wirtz, Columbus State Community College, Columbus, Ohio

Brad Richmand, ACCA, Washington, District of Columbia

Greg Perakes, Tennessee Technology Center at Murfreesboro, Murfreesboro, Tennessee

Thomas Schafer, Macomb Community College, Warren, Michigan

Larry Penar, Refrigeration Service Engineers Society (RSES), Des Plaines, Illinois

Johnnie O. Bellamy, Eastfield College Continuing Education, Mesquite, Texas

John Corbitt, Eastfield College Continuing Education, Mesquite, Texas

Dick Shaw, ACCA, Washington, D.C.

Hugh Cole, Gwinnett Technical Institute, Lawrenceville, Georgia

Norman Christopherson, San Jose City College, San Jose, California

Barry Burkan, Apex Technical School, New York, New York

Victor Cafarchia, El Camino College, Torrance, California

Cecil W. Clark, American Trades Institute, Dallas, Texas

Bill Litchy, Training Materials Manager, Scotsman Ice Systems, Vernon Hills, Illinois

Danny Moore, Director of Technical Support, Hoshizaki America, Peachtree City, Georgia

Lawrence D. Priest, Tidewater Community College, Virginia Beach, Virginia

Mitch Rens, Service Publications Manager, Manitowoc Ice, Inc., Manitowoc, Wisconsin

Terry M. Rogers, Midlands Technical College, West Columbia, South Carolina

Russell Smith, Athens Technical College, Athens, Georgia

The authors would like to thank the following individuals and companies for their valuable contributions to the 7th edition, 25th Anniversary Edition text:

Joseph R. Pacella, MS ISM, LEED AP, Associate Professor, Ferris State University for help in providing information on the USGBC and LEED rating systems.

John Pastorello, CEO, Refrigeration Technologies, Anaheim, CA, for supplying the technical information and digital photographs on basic and advanced leak detection in Unit 8, Leak Detection, System Evacuation, and System Cleanup.

Robert Nash, Jr., Senior Engineer, Emerson Climate Technologies, Ferris State University HVACR graduate for providing technical information and digital photographs which assisted in writing the carbon dioxide (CO₂) refrigeration system section in Unit 26.

Nick Strickland, Market Development Manager, DuPont Corporation for providing technical information on refrigerants, refrigerant blends, and their compatible oils.

Michael D. Stuart, T/IRT Level III Thermographer (Certified per ASNT Standards), Senior Product Marketing Manager, Fluke Corporation for his unselfish assistance in writing Unit 39, Residential Energy Auditing by providing many self-authored, published technical articles on residential energy auditing, and many digital photographs incorporating infrared technology which enhanced the quality of Unit 39. Special thanks to the Fluke Corporation.

Patrick Pung, Maintenance Mechanic, Selfridge Air National Guard Base, Ferris State University HVACR Technology graduate for providing technical information and digital photographs on closed-loop, slinky, geothermal heat pump systems used in enhancing Unit 44, Geothermal Heat Pump Systems.

William M. (Bill) Johnson for providing most of the proofreading and comments for the 7th edition and special 25th anniversary edition of this book.

Joe Parsons, Vice President, Earthlinked Technologies Incorporated for providing technical information and digital photographs of Direct GeoExchange heat pump systems used in the enhancement of Unit 44, Geothermal Heat Pumps.

Arn McIntyre, MS Eng., Energy Center Director at Ferris State University for his assistance in locating technical literature and contacts for writing Unit 39, Residential Energy Auditing.

Jason Mauric, Ferris State University HVACR Technology student for his assistance in photography and equipment used in writing the Residential Energy Auditing unit.

Mary Jo Gentry, Marketing Communications Manager, Richie Engineering Company–Yellow Jacket Products Division for providing many digital images of the Richie Engineering Company's tools and equipment used in the HVACR field.

Frank Spevak, Marketing and Sales Manager, and **Paul Morin**, Technical Sales Specialist, The Energy Conservatory, for providing technical assistance and digital photographs used in writing Unit 39, Residential Energy Auditing.

Jerry Ackerman, Director of Marketing and Communications, Clearwater Systems Corporation for providing technical literature and digital photographs on the latest technology in chemical-free water treatment for cooling towers used in Unit 48, Cooling Towers and Pumps.

Victor DesRoches, Marketing Coordinator, LAKOS Separators and Filtration Solutions, Fresno, CA, for providing technical literature and photographs on centrifugal particle separators which enhanced the quality of Unit 48, Cooling Towers and Pumps.

Phyllis Shaw, Marketing Communications Supervisor, Sporlan Division–Parker Hannifin Corporation for providing countless digital photographs and system schematics which can be viewed throughout this book. Quality technical literature provided has also updated and enhanced many units in this new edition and also throughout the entire book.

Fieldpiece Instruments Corporation, for providing quality digital photos of their modern HVACR tools and equipment.

Greg Sundheim, President, and **Dave Boyd**, Vice President, Appion Corporation, for providing both technical literature and quality digital photographs which have greatly enhanced Unit 8, Leak Detection, System Evacuation, and System Cleanup.

National Refrigerants, Inc., Philadelphia, PA, for their technical information on refrigerants and retrofitting refrigeration systems.

Karl Huffman, President, Hedrick Associates - Marley Cooling Towers, Grand Rapids, MI, Ferris State University HVACR Graduate for his assistance in providing technical literature and photographs on chemical-free water treatment using pulse technology for cooling towers in Unit 48, Cooling Towers and Pumps.

Paul Fauci of Slant/Fin Corporation for assistance with the artwork incorporated in the Heating Units of the text.

Laura Harris at WaterFurnace for images of the Envision NXW reverse-cycle chiller.

Thomasena Philen of Daikin AC for valuable assistance with the Variable Refrigerant Flow content.

Brian G. Good of GI Industries for high quality images and technical input on duct cleaning equipment.

Tony Quick of Air System Components, Trion Division for high quality humidifier images.

The authors would like to thank the following individuals and companies for their valuable contributions to the 8th edition text:

John Campbell, Renton Technical College, Renton, WA.

Jason Leeds, North Central Kansas Tech, Hayes, KS.

Raul Lopez, Houston Community College, Houston, TX.

Dennis Matney, Ivy Tech Community College, Indianapolis, IN.

Tim Cary, Dwyer Instruments, Inc., Michigan City, IN for high quality images of airflow measuring instruments.

Robert Thompson, Dwyer Instruments, Inc., Michigan City, IN for help with technical data regarding airflow measuring and the use of airflow measuring instrumentation.

Deborah Keny, SPX Cooling Technologies, Overland Park, KS for high quality images of cooling towers and cooling tower configurations.

Tim Snyder, Marketing Manager, The Chemours Company (Formerly DuPont), for his continued support with up-to-date refrigerant technologies, artwork, and technical support. Tim is a true friend of the authors and the industry.

David Foster, Uniweld Products, Inc., Fort Lauderdale, FL, for providing high quality images of a number of tools and pieces of test equipment for inclusion in the book. An all-around nice guy and a long-time supporter of the writing team and the industry.

Eugene Ziegler, Sales Engineer and Training Materials Manager, Sporlan, Parker Hannifin, for providing test instrumentation for inclusion in the text.

Dave Boyd, Vice President, Appion Star Performance, Englewood, CO, for providing test instrumentation for inclusion in the text. A nice guy and a great harmonica player.

John Levey, President, Oilheat Associates, Wantagh, NY for numerous high quality images and technical assistance with the Oil Heat Unit. A true gentleman and a close, personal friend.

C. Curtis Lawson, Sr. Technical Service Consultant, DuPont Refrigerants for his assistance in providing technical literature on the HVAC/R industry's newer refrigerants and refrigerant blends.

Dr. Stanley Friedman, retired Neurologist, Phoenix, Arizona for his thorough proofreading of many units in this 8th edition.

Keith Satterthwaite, Lincoln Technical Institute, Union NJ for his insight and valuable contributions to Unit 36.

AVENUE FOR FEEDBACK

The authors would appreciate feedback from students and/or instructors. They can be reached through Cengage Learning in Clifton Park, New York, or through the following e-mail addresses:

John A. Tomczyk
tomczykjohn@gmail.com

Eugene Silberstein
eugene.silberstein@yahoo.com

SECTION 1

THEORY OF HEAT

Units

Introduction

Unit 1 Heat, Temperature, and Pressure

Unit 2 Matter and Energy

Unit 3 Refrigeration and Refrigerants

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.

HISTORY OF REFRIGERATION AND AIR-CONDITIONING (COOLING)

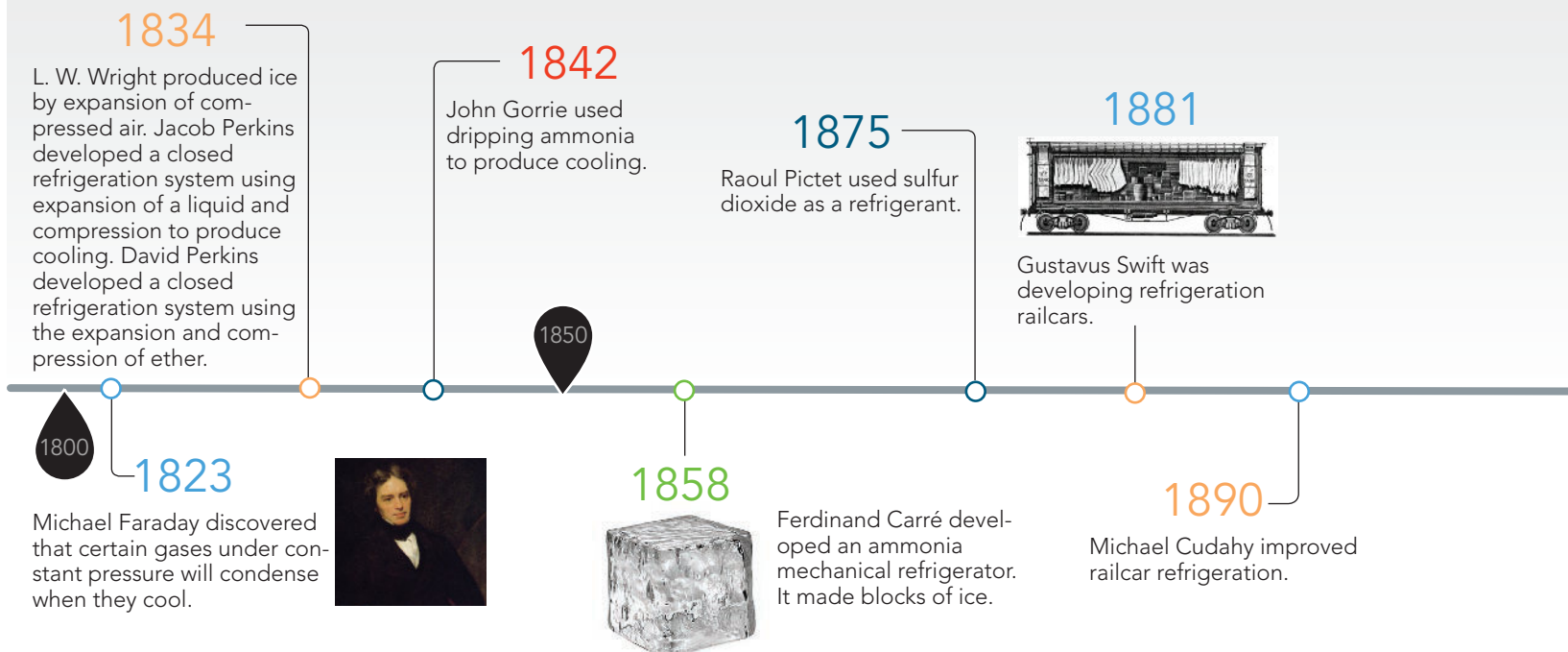
Most evidence indicates that the Chinese, as early as 1000 B.C., were the first to store ice and snow in order to cool wine and other food products. Early Greeks and Romans used underground pits, which were insulated with straw and

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



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.

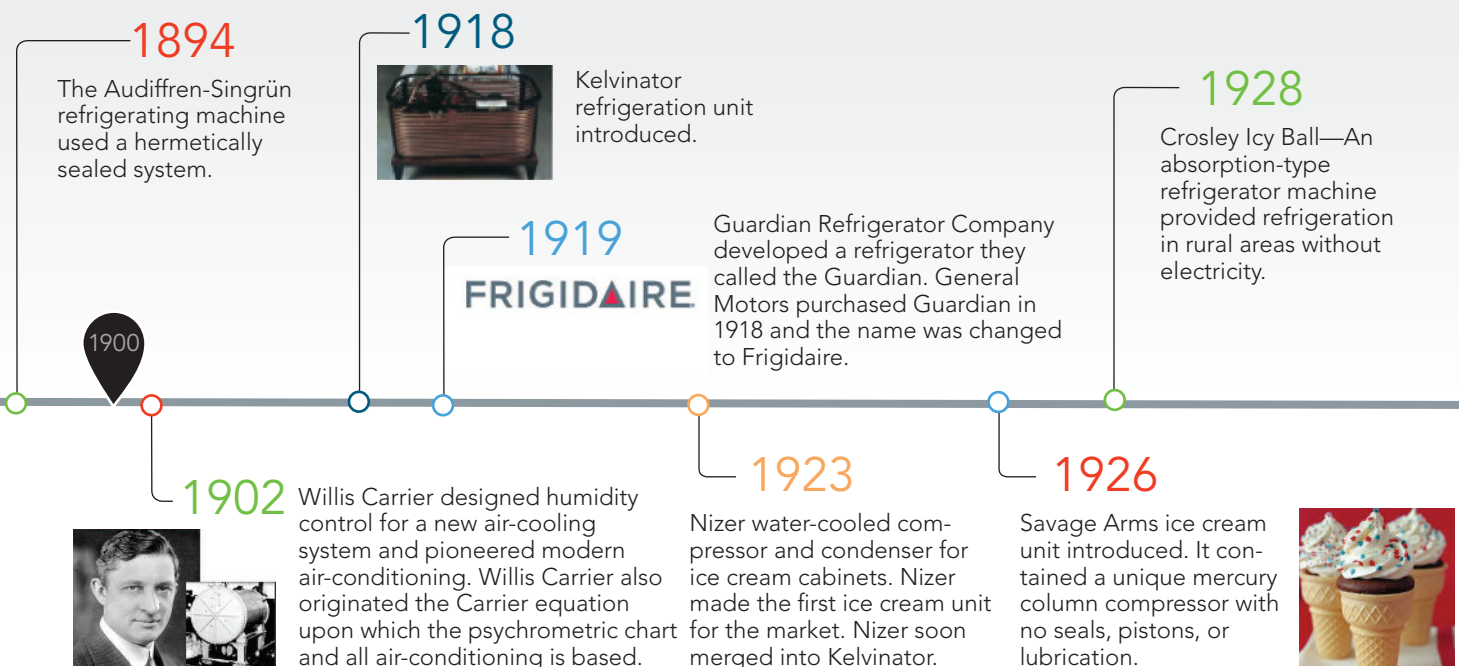
In 1918, the Kelvinator company, originally named the Electro Automatic Refrigeration Corporation, came into being and sold the first Kelvinator household units.

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. In 1923–1926, 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



compressor. Three engineering changes made these compressors successful:

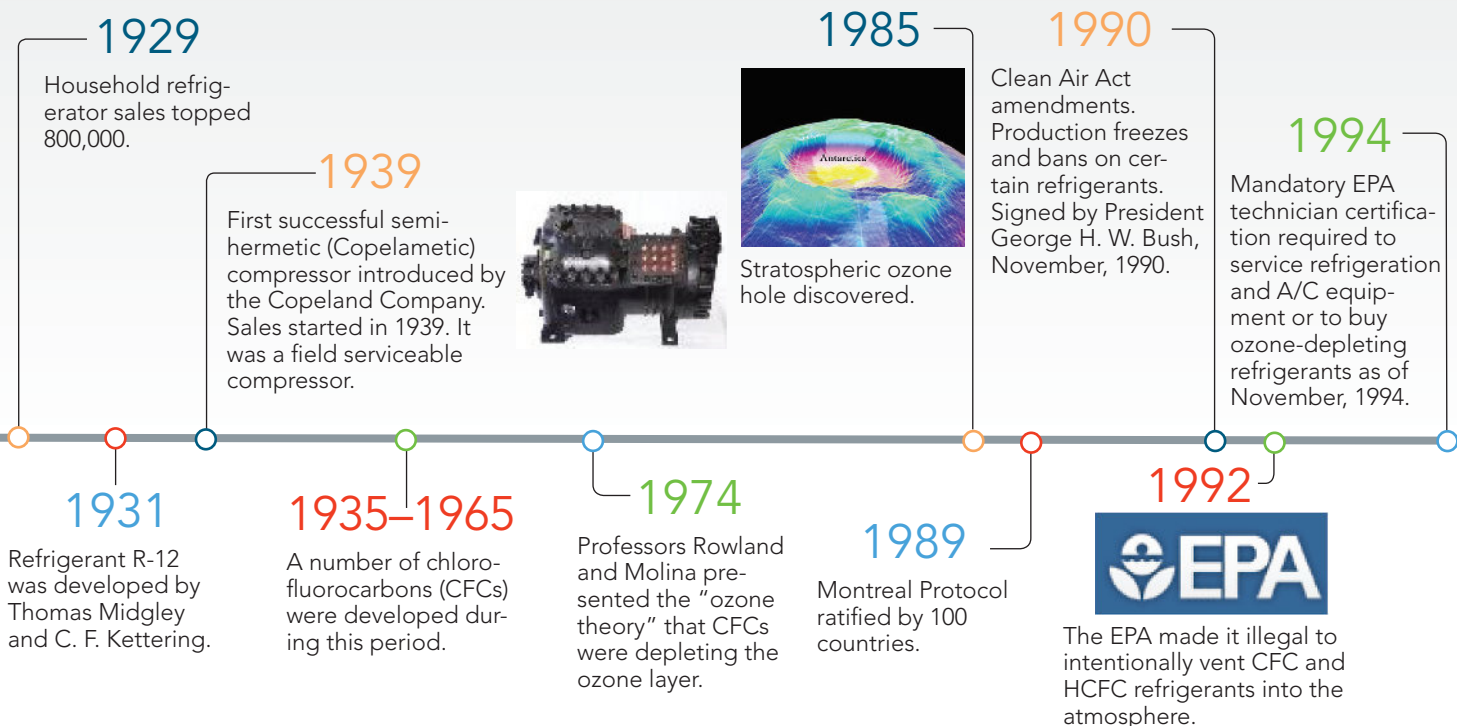
1. Cloth-insulated motor windings were replaced with Glyptal insulation.
2. Neoprene insulation replaced porcelain enamel in the electric terminals.
3. Valves were redesigned to improve efficiency.

Many different refrigerants have been developed over the years. The refrigerant 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 HVAC/R 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.

TIME LINE



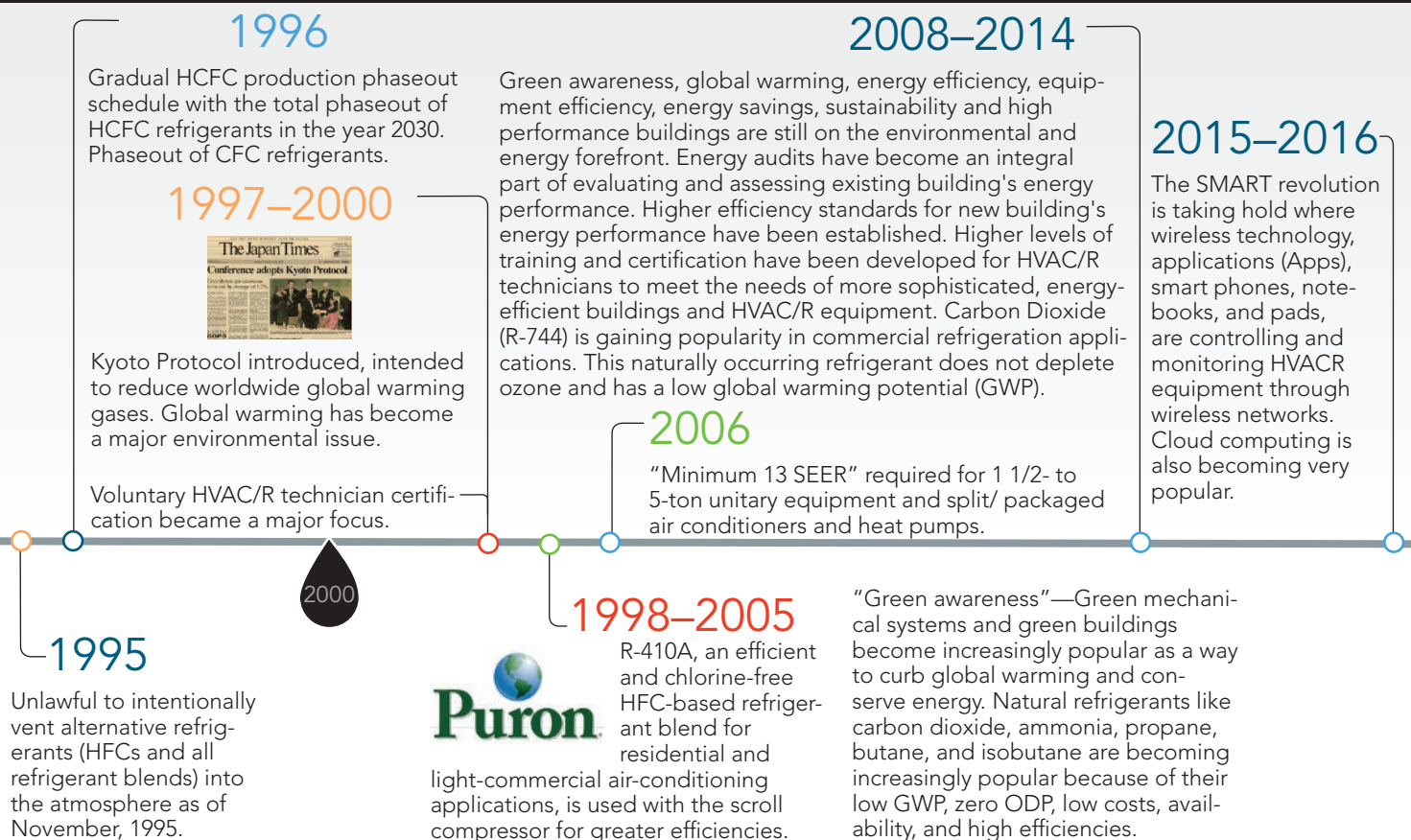
- 1998 (June)—The EPA proposed new regulations on recovery/recycling standards, equipment leak rates, and alternative refrigerants.
- 2004—35% reduction in HCFC refrigerant production.
- 2007—HCFC reduction on production was accelerated from 65% to 75% from the baseline 1989 production year.
- 2010—HCFC-22 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.
- 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 HVAC/R technician certification became a major focus of the industry. From 1998 to the present, the major players in voluntary HVAC/R 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 [this information updated from multiple sources, including <http://www.climate.gov/news-features/videos/2014-global-temperature-recap>]. 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 142 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 over 5 million commercial buildings and over 132 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 millions 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. It was enhanced in 2009 and is currently operating under Version 3 of the rating system. All of the information for LEED ratings is available at <http://www.usgbc.org/>. Version 4 of the LEED program was scheduled to be put into effect in July 2015 and, at the time of this writing, the implementation of the new version is on schedule.

The USGBC membership, which is composed of every sector of the building industry and consists of over 9,000

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 nine possible LEED rating categories, and each is assigned individual points for reaching accreditation. Listed here are the nine categories (separate rating systems) and possible points per categories.

Category	Points Possible
New Construction	110
Existing Buildings (Operation & Maintenance)	92
Commercial Interiors	110
Core & Shell	110
Schools	110
Retail	110
Healthcare	110
Homes	136
Neighborhood Development	110

Points are awarded in each category depending on how well the building meets the category’s requirements. For example, the following information is taken from the New Construction (NC) LEED Rating System. Keep in mind that each system has different point-generation possibilities. The LEED NC system requires that a building earn a minimum of 40 points to meet minimum requirements out of a possible 110 points. There are four levels of certification according to the point system:

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

A LEED NC certified building means that it has achieved at least a minimum standard as judged in the following seven categories prior to any points being awarded toward a LEED rating.

Category	Points Possible
Sustainable Sites	26
Water Efficiency	10
Energy & Atmosphere	35
Materials & Resources	14
Indoor Environmental Quality	15
Innovation & Design Process	6
Regional Priority Credits	4
	<hr/> 110

The Energy & Atmosphere category has a possible 35 points, with potentially 33 of them directly linked to HVAC systems. This category for New Construction (NC) addresses such items as the facility’s basic consumption of energy, its optimization of energy consumption, system commissioning and refrigerant management, and use of on-site renewable energy. Optimizing building facilities’ performance can equate to a possible 19 out of 35 points. These points would equate to installing an HVAC system that improves efficiency by 48% for new construction or 44% for existing HVAC systems and constitute a large portion of the possible points, which provides opportunities in building renovation.

The Indoor Environmental Quality category has a possible 15 points, with potentially 7 of them directly linked to HVAC systems. This category has multiple possibilities: HVAC systems can affect outdoor air-delivery monitoring of facility ventilation, minimum air changes in buildings for removing harmful volatile organic compounds (VOCs), electronic thermal control systems, and thermal comfort design and verification.

In summary, 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 as well as the HVAC efficiencies listed above. 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 1,000-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 teepees, 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 HVAC/R industry is rapidly changing due to advancements in technology being spurred on by the need for increased energy efficiencies. The career opportunities available in HVAC/R 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 HVAC/R 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 HVAC/R 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 HVAC/R 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 fossil 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 HVAC/R 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