

Contents

| | |
|-----------------------|------|
| List of Figures | xi |
| Preface..... | xv |
| Author | xvii |

SECTION A Water Chillers: Fundamentals, Application, and Operation

PART I Chiller Fundamentals

| | | |
|------------------|--|----|
| Chapter 1 | Refrigeration Machines | 5 |
| | Vapor Compression Refrigeration | 6 |
| | Refrigeration Cycle..... | 6 |
| | Refrigerants | 8 |
| | Absorption Refrigeration..... | 11 |
| | Absorption Refrigeration Cycle..... | 11 |
| | Refrigerants | 13 |
| | Vapor Compression Cycle Water Chillers..... | 15 |
| | Scroll Compressors..... | 15 |
| | Rotary Screw and Centrifugal Compressors..... | 16 |
| | Electric-Drive Chillers | 20 |
| | Engine-Drive Chillers | 22 |
| | Condensing Medium | 23 |
| | Absorption Chillers | 24 |
| | Lithium Bromide Absorption Chillers | 24 |
| | Ammonia Absorption Chillers | 25 |
| | Chilled Water for HVAC Applications..... | 26 |
| | Determining the Chilled Water Supply Temperature | 27 |
| | Establishing the Temperature Range..... | 29 |
| Chapter 2 | Chiller Configurations..... | 31 |
| | The Single-Chiller System | 31 |
| | Multichiller Systems..... | 31 |
| | One-Pump Parallel Configuration | 33 |
| | Multiple-Pump Parallel Configuration | 34 |
| | Primary–Secondary Parallel Configuration..... | 35 |
| | Variable Primary Flow Parallel Configuration | 37 |
| | System Peak Cooling Load and Load Profile | 38 |

| | |
|---|----|
| Selecting Water Chillers..... | 42 |
| Basic Chiller Requirements..... | 42 |
| Part Load Efficiency..... | 42 |
| Load versus Capacity | 44 |
| Atmospheric Impacts..... | 46 |
| Mixed Energy Source Chiller Systems | 47 |

PART II Chiller Design and Application

| | | |
|------------------|--|-----|
| Chapter 3 | Chilled Water System Elements..... | 53 |
| | Chiller Placement and Installation..... | 53 |
| | Chilled Water Piping..... | 55 |
| | Piping Materials and Insulation Requirements | 55 |
| | Water Expansion and Air Removal | 61 |
| | Water Treatment | 63 |
| | Pump Selection and Piping | 65 |
| | Pump Basics | 65 |
| | Pump Head and Horsepower..... | 66 |
| | Variable Flow Pumping..... | 69 |
| Chapter 4 | Chilled Water System Control and Performance | 71 |
| | Start-Up Control..... | 71 |
| | Capacity Control | 72 |
| | Refrigerant Flow Control..... | 72 |
| | Sequencing Multiple Chillers..... | 74 |
| | Optimizing Chilled Water Supply Temperature..... | 76 |
| | Variable Flow Pumping Control | 77 |
| Chapter 5 | Cooling Thermal Energy Storage | 81 |
| | Economics of Thermal Energy Storage | 81 |
| | Available Technologies..... | 86 |
| | Chilled Water Storage Systems | 86 |
| | Ice Storage | 88 |
| | Phase Change Materials Storage Systems..... | 92 |
| | Application of TES..... | 93 |
| Chapter 6 | Special Chiller Considerations..... | 95 |
| | Noise and Vibration..... | 95 |
| | Electrical Service | 98 |
| | Chiller Heat Recovery..... | 100 |

PART III Chiller Operations and Maintenance

Chapter 7 Chiller Operation and Maintenance..... 105

 Chiller Commissioning 105

 Chiller Maintenance..... 107

 Chiller Performance Troubleshooting.....115

 Selection or Design Problems.....116

 Installation Problems.....116

 Refrigerant Management Program.....118

Chapter 8 Buying a Chiller 123

 Defining Chiller Performance Requirements..... 123

 Economic Evaluation of Chiller Systems..... 125

 First Costs..... 125

 Annual Recurring Costs..... 127

 Nonrecurring Repair and Replacement Costs..... 128

 Total Owning and Operating Cost Comparison..... 128

 Procurement Specifications..... 128

SECTION B Cooling Towers: Fundamentals, Application, and Operation

PART I Cooling Tower Fundamentals

Chapter 9 Cooling Tower Fundamentals 133

 Cooling Towers in HVAC Systems 133

 Condenser Water System Elements..... 134

 Nomenclature 135

 Cooling Tower Heat Transfer 137

 Cooling Tower Performance Factors.....141

 Basic Cooling Tower Configuration.....141

Chapter 10 Cooling Tower Components.....147

 Fill147

 Spray Fill147

 Splash Fill..... 148

 Film Fill..... 149

 Structural Frame 150

 Wooden Structure..... 150

 Steel Structure 150

 Other Structural Systems..... 152

| | |
|---|-----|
| Casing..... | 152 |
| Wet Decks/Water Distribution | 153 |
| Basins | 153 |
| Intake Louvers and Drift Eliminators..... | 154 |
| Fans, Motors, and Drives | 154 |
| Fans..... | 154 |
| Motors..... | 159 |
| Mechanical Drives..... | 161 |

PART II Cooling Tower Design and Application

| | |
|---|-----|
| Chapter 11 Tower Configuration and Application | 165 |
| Types of Cooling Towers..... | 165 |
| Counterflow versus Crossflow | 165 |
| Mechanical Draft | 169 |
| Capacity and Performance Parameters | 170 |
| Temperature Range and Approach | 170 |
| Ambient Wet Bulb Temperature..... | 171 |
| Condenser Water Heat Rejection..... | 171 |
| Chiller/Cooling Tower Configuration | 172 |
| Tower Placement and Installation | 174 |
| Cooling Tower Piping..... | 179 |
| Condenser Water Piping | 179 |
| Makeup Water Piping | 182 |
| Drain and Overflow Piping..... | 184 |
| Multiple Towers or Cells Piping..... | 184 |
| Pump Selection, Placement, and Piping..... | 187 |
| Evaporative Condensers and Coolers..... | 191 |
| | |
| Chapter 12 Cooling Tower Controls | 193 |
| Start/Stop Control | 193 |
| Capacity Control | 196 |
| Fan Cycling..... | 197 |
| Fan Speed Control | 199 |
| Tower Staging | 202 |
| Makeup Water Control | 203 |
| Operating Safety Controls..... | 203 |
| | |
| Chapter 13 Condenser Water Treatment..... | 205 |
| Deposition Control | 205 |
| Corrosion Control..... | 211 |

| | |
|--|-----|
| Galvanic Corrosion..... | 211 |
| White Rust..... | 213 |
| Biological Fouling Control..... | 215 |
| Biological Fouling..... | 215 |
| Microbiologically Induced Corrosion..... | 216 |
| Foam Control..... | 217 |
| Water Treatment Control Systems..... | 217 |
| Alternative Water Treatment Methods..... | 219 |
| Sidestream Filtration..... | 219 |
| Ozone Treatment..... | 219 |
| UV Treatment..... | 220 |
| Magnetic Treatment..... | 220 |
| Treatment for Wooden Towers..... | 221 |
| Chemical Storage and Safety..... | 222 |
| Spill Control..... | 222 |
| Safety Showers and Eyewash Stations..... | 222 |

| | |
|---|-----|
| Chapter 14 Special Tower Considerations..... | 225 |
| Basin and Outdoor Piping Freeze Protection..... | 225 |
| Waterside Economizer Cycle..... | 227 |
| Noise and Vibration..... | 229 |
| Plume Control..... | 232 |
| Fire Protection..... | 235 |
| <i>Legionella</i> Control..... | 236 |

PART III Cooling Tower Operations and Maintenance

| | |
|--|-----|
| Chapter 15 Cooling Tower Operation and Maintenance..... | 243 |
| Tower Commissioning..... | 243 |
| Cooling Tower Maintenance..... | 245 |
| Water Treatment Management..... | 245 |
| Mechanical Maintenance..... | 246 |
| Induction/Venturi Tower Maintenance..... | 249 |
| Heat Exchanger Maintenance..... | 250 |
| Tower Performance Troubleshooting..... | 251 |
| Selection Problems..... | 251 |
| Installation Problems..... | 252 |
| Maintenance Problems..... | 252 |
| Enhancing Tower Performance..... | 253 |
| Cooling Towers in Freezing Climates..... | 253 |

| | |
|---|-----|
| Winter Tower Operation..... | 255 |
| Winter Tower Shutdown..... | 255 |
| · 16 Buying a Cooling Tower..... | 257 |
| Defining Tower Performance Requirements..... | 257 |
| CTI Ratings and Performance Guarantees..... | 258 |
| Economic Evaluation of Alternative Cooling Tower Systems.... | 261 |
| First Costs..... | 261 |
| Annual Recurring Costs..... | 262 |
| Nonrecurring Repair and Replacement Costs..... | 264 |
| Total Owning and Operating Cost Comparison..... | 265 |
| Procurement Specifications..... | 265 |
| Water Treatment Program Contracting..... | 265 |
| Chapter 17 <i>In Situ</i> Tower Performance Testing..... | 267 |
| Why <i>In Situ</i> Testing?..... | 267 |
| Testing Criteria and Methods..... | 267 |
| Tower Installation Requirements for Testing..... | 271 |
| Appendix A: Design Ambient Wet Bulb Temperatures (Recommended for Cooling Tower Selection)..... | 273 |
| Appendix B1: Centrifugal Compressor Water Chillers..... | 277 |
| Appendix B2: Scroll Compressor Water Chillers..... | 303 |
| Appendix B3: Rotary Screw Compressor Water Chillers..... | 323 |
| Appendix B4: Induced Draft Cooling Towers..... | 351 |
| Appendix B5: Closed-Circuit Liquid Coolers..... | 361 |
| Appendix C: References and Resources..... | 371 |
| Index | 375 |