

Table of Contents

<i>Preface</i>	<i>ix</i>	
CHAPTER 1	Residential Energy Basics	3
Objectives	3	
1.1 Introduction	3	
1.2 Thermal Comfort	5	
1.3 Heat, Heat Transfer, and Thermodynamics	6	
1.4 The Need for Auxiliary Heating	13	
1.5 Energy Conservation versus Energy Supply	15	
1.6 Unit Pricing of Thermal Energy	27	
1.7 Cooling and Ventilation Considerations	30	
Summary	36	
Key Terms	36	
Questions and Exercises	36	
CHAPTER 2	Space Heating and Domestic Water Heating Loads	39
Objectives	39	
2.1 Introduction	39	
2.2 Design Space Heating Load	40	
2.3 Conduction Heat Losses	41	
2.4 Foundation Heat Loss	45	
2.5 Infiltration Heat Loss	53	
2.6 Example of Complete Heating Load Estimate	56	
2.7 Computer-Aided Heating Load Calculations	59	
2.8 Estimating Annual Heating Energy Use	61	
2.9 Estimating Domestic Water-Heating Loads	65	
Summary	69	
Key Terms	69	
Questions and Exercises	69	
CHAPTER 3	Universal Hydronic Concepts	73
Objectives	73	
3.1 Introduction	73	
3.2 Fundamentals of Closed-Loop Hydronic Circuits	74	
3.3 Properties of Water and Water-Based Fluids	78	
3.4 Static Pressure	85	
3.5 Flow Rate and Flow Velocity	86	
3.6 Head Energy	88	
Summary	97	
Key Terms	97	
Questions and Exercises	97	

CHAPTER 4	Essential Hydronic Hardware	101
	Objectives	101
	4.1 Introduction	101
	4.2 Auxiliary Boilers	102
	4.3 Hydronic Piping, Fittings, and Valves	107
	4.4 Circulators	132
	4.5 Hydraulic Separation	158
	4.6 Air Elimination and Air Management	165
	4.7 Expansion Tanks	173
	4.8 Brazed-Plate Heat Exchangers	181
	Summary	186
	Key Terms	186
	Questions and Exercises	187
CHAPTER 5	Low-Temperature Heat Emitters and Distribution Systems	191
	Objectives	191
	5.1 Introduction	191
	5.2 Fin-Tube Baseboard	197
	5.3 Panel Radiators	208
	5.4 Hydronic Fan Coils	220
	5.5 Hydronic Radiant Panel Heating	230
	5.6 Heated Slab-on-Grade Floors	233
	5.7 Heated Thin Slabs	244
	5.8 Above-Floor Tube and Plate Systems	247
	5.9 Radiant Wall and Ceiling Panels	250
	5.10 Thermal Mass of Heat Emitters	253
	Summary	255
	Key Terms	255
	Questions and Exercises	256
CHAPTER 6	Control Principles and Hardware	259
	Objectives	259
	6.1 Introduction	259
	6.2 Closed-Loop Control Fundamentals	260
	6.3 Controller Outputs	261
	6.4 On/Off Heat Source Control	264
	6.5 Control of Modulating Heat Sources	265
	6.6 Controlling the Heat Output of Heat Emitters	267
	6.7 Outdoor Reset Control	270
	6.8 Differential Temperature Control	279
	6.9 Heat Metering (fully instrumented)	287
	6.10 Temperature Sensors and Sensor Placement	288
	6.11 Switches, Relays, and Ladder Diagrams	292
	Summary	302
	Key Terms	303
	Questions and Exercises	303

CHAPTER 7	Solar Fundamentals	307
Objectives		307
7.1 Introduction		307
7.2 A Brief History of Solar Heating		308
7.3 Solar Radiation Fundamentals		311
7.4 Solar Geometry and Availability		313
Summary		327
Additional Resources		327
Key Terms		328
Questions and Exercises		328
CHAPTER 8	Solar Thermal Collectors	331
Objectives		331
8.1 Introduction		331
8.2 Optical Properties of Solar Collector Materials		332
8.3 Flat-Plate Solar Collectors		333
8.4 Evacuated Tube Solar Collectors		335
8.5 Solar Collectors for Pool Heating		341
8.6 Thermal Performance of Solar Collectors		342
8.7 Mounting Solar Collectors		356
Summary		370
Additional Resources		371
Key Terms		371
Questions and Exercises		372
CHAPTER 9	Thermal Storage Tanks	375
Objectives		375
9.1 Introduction		375
9.2 Unpressurized Thermal Storage Tanks		376
9.3 Pressurized Thermal Storage Tanks		383
9.4 Stratification in Thermal Storage Tanks		394
9.5 Heat Capacity and Heat Loss of Thermal Storage Tanks		399
9.6 Storage-Enhanced On-Demand Domestic Water Heating		407
9.7 Flow Reversal Through Storage		415
Summary		418
Key Terms		418
Questions and Exercises		418
CHAPTER 10	Antifreeze-Protected Solar Combisystems	421
Objectives		421
10.1 Introduction		421
10.2 Antifreeze Fluids		422
10.3 Design Details for Antifreeze-Based Systems		422
10.4 Expansion Tanks for Antifreeze-Protected Solar Collector Circuits		425
10.5 Antifreeze-Protected Solar Domestic Water Heating Systems		431
10.6 Antifreeze-Protected Solar Combisystems		437
Summary		442
Additional Resources		459
Key Terms		460
Questions and Exercises		460
		460

CHAPTER 11	Drainback-Protected Solar Combisystems	463
Objectives		463
11.1 Introduction		463
11.2 Drainback-Protected Systems Using Unpressurized Thermal Storage		464
11.3 Drainback-Protected Systems Using Pressurized Thermal Storage		465
11.4 Design Details for Drainback Systems		468
11.5 Drainback-Protected Solar Domestic Water Heating Systems		485
11.6 Examples of Drainback-Protected Combisystems		487
Summary		500
Additional Resources		500
Key Terms		501
Questions and Exercises		501
CHAPTER 12	Estimating Solar Combisystem Performance Using the <i>f</i>-Chart Method	505
Objectives		505
12.1 Introduction		505
12.2 Simplified Version of the <i>f</i> -Chart Method for Manual Calculations		508
12.3 Using F-CHART Software		515
Summary		522
Additional Resources		522
Key Terms		522
Questions and Exercises		523
CHAPTER 13	Air-to-Water Heat Pump Systems	527
Objectives		527
13.1 Introduction		527
13.2 Heat Pump Fundamentals		529
13.3 Thermal Performance of Heat Pumps		534
13.4 Air-to-Water Heat Pumps		537
13.5 Thermal Performance of Air-to-Water Heat Pumps		542
13.6 Design Details for Air-to-Water Heat Pumps		546
13.7 Thermal Storage and Air-to-Water Heat Pumps		553
13.8 Examples of Combisystems Using Air-to-Water Heat Pump Systems		562
13.9 Performance Simulation Software and Comparison with Geothermal Heat Pumps		578
Summary		582
Key Terms		582
Questions and Exercises		582
CHAPTER 14	Water-to-Water Geothermal Heat Pump Systems	585
Objectives		585
14.1 Introduction		585
14.2 Water-to-Water Heat Pumps		586
14.3 Thermal Performance of Water-to-Water Heat Pumps		588
14.4 Design Details for Water-to-Water Heat Pump Systems		594
14.5 Water-to-Water Heat Pumps Supplied from Ground Water		600
14.6 Water-to-Water Heat Pumps Supplied by Earth Loops		614
14.7 Earth Loop Piping and Pipe Joining Procedures		622

14.8	Earth Loop Design	629
14.9	Earth Loop Sizing	650
14.10	Filling and Purging Earth Loops	662
14.11	Examples of Combisystems Using Geothermal Water-to-Water Heat Pumps	670
	Summary	693
	Additional Resources	693
	Key Terms	694
	Questions and Exercises	694
CHAPTER 15	Wood-Fired and Pellet-Fired Hydronic Systems	699
	Objectives	699
15.1	Introduction	699
15.2	The Evolution of Wood-Fueled Hydronic Heating	700
15.3	Wood as a Heating Fuel	706
15.4	Outdoor Wood-Fired Hydronic Heaters	714
15.5	Natural Draft Wood-Fired Boilers	721
15.6	Wood-Gasification Boilers	725
15.7	Pellet-Fired Boilers	727
15.8	Design Details for Wood- and Pellet-Fired Boiler Systems	730
15.9	Sizing Wood-Gasification and Pellet-Fired Boilers	759
15.10	Example Systems	764
	Summary	793
	Additional Resources	794
	Key Terms	794
	Questions and Exercises	794
CHAPTER 16	Economic Evaluation Methods and Tools	797
	Objectives	797
16.1	Introduction	797
16.2	Basic Financial Calculations	798
16.3	Simple Payback	801
16.4	Monthly Owning and Operating Cost	803
16.5	Return on Investment	807
	Summary	810
	Key Terms	810
	Questions and Exercises	810
	<i>Appendix A Schematic symbols</i>	813
	<i>Appendix B R-values of common building materials</i>	815
	<i>Appendix C Useful conversion factors and data</i>	817
	<i>Glossary</i>	819
	<i>Index</i>	839