



# CONTENTS

CHAPTER 1.	Extraterrestrial Solar Radiation	1
1.1	The Sun	1
1.2	The Solar Constant	3
1.3	Spectral Distribution of Extraterrestrial Radiation	5
CHAPTER 2.	Solar Radiation at Earth's Surface	8
2.1	Definitions	8
2.2	Variation of Extraterrestrial Radiation	9
2.3	Attenuation of Beam Radiation	9
2.4	Diffuse Radiation at the Ground	13
2.5	Direction of Beam Radiation	14
2.6	Direction of Diffuse Radiation	18
2.7	Solar Time and the Equation of Time	18
CHAPTER 3.	Solar Radiation: Measurements Data, and Estimation	21
3.1	Definitions	21
3.2	Radiation Measurements, Instruments	23
3.3	Solar Radiation Data	25
3.4	Estimation of Average Solar Radiation	29
3.5	Estimation of Hourly Radiation from Daily Data	43
3.6	Ratio of Beam Radiation on Tilted Surface to That on Horizontal Surface	48
3.7	Ratio of Total Radiation on a Tilted Surface to That on Horizontal Surface	53
3.8	Effects of Receiving Surface Orientation and Motion	55
CHAPTER 4.	Selected Topics in Heat Transfer	61
4.1	The Electromagnetic Spectrum	61
4.2	Photon Radiation	62
4.3	The Blackbody, a Perfect Absorber and Emitter of Radiation	63
4.4	Planck's Law and Wien's Displacement Law	64

4.5	Stefan-Boltzmann Formula	66
4.6	Radiation Tables	66
4.7	Radiation Intensity and Flux	67
4.8	Infrared Radiation Heat Transfer Between Gray Surfaces	74
4.9	Sky Radiation	76
4.10	Radiation Heat Transfer Coefficient	77
4.11	Natural Convection Between Parallel Flat Plates	77
4.12	Convection Suppression Using Honeycombs	81
4.13	Forced Convection Between Parallel Flat Plates	82
4.14	Miscellaneous Heat Transfer Relations	83
CHAPTER 5. Radiation Characteristics of Opaque Materials		85
5.1	Absorptance and Emittance	85
5.2	Kirchoff's Law	87
5.3	Reflection from Surfaces	89
5.4	Relationships Among Absorptance, Emittance, and Reflectance	94
5.5	Measurements of Surface Radiation Properties	95
5.6	Selective Surfaces	98
5.7	"Black" Surfaces	102
5.8	Specularly Reflecting Surfaces	102
CHAPTER 6. Transmission of Radiation Through Partially Transparent Media		108
6.1	Reflection at Interfaces	108
6.2	Absorption of Radiation in Partially Transparent Media	111
6.3	Transmittance-Absorptance Product	113
6.4	Spectral Dependence of Transmittance	115
6.5	Effects of Surface Layers on Transmittance	118
CHAPTER 7. Flat-Plate Collectors		120
7.1	General Description of Flat-Plate Collectors	121
7.2	The Basic Flat-Plate Energy Balance Equation	122
7.3	General Characteristics of Flat-Plate Solar Collectors	123
7.4	Collector Overall Heat Transfer Coefficient	125
7.5	Temperature Distribution Between Tubes, and the Collector Efficiency Factor	138
7.6	Temperature Distribution in Flow Direction	143
7.7	Collector Heat Removal Factor and Flow Factor	146
7.8	Mean Plate Temperature	151
7.9	Effective Transmittance-Absorptance Product	153
7.10	Effects of Dust and Shading	156

7.11	Heat Capacity Effects in Flat-Plate Collectors	158
7.12	Other Collector Geometries	162
7.13	Short-Term Collector Performance	168
7.14	Long-Term Collector Performance	172
7.15	Practical Considerations for Flat-Plate Collectors	175
CHAPTER 8. Focusing Collectors		178
8.1	The Solar Disk and Theoretical Solar Images	180
8.2	Concentrators, Receivers, and Orienting Systems	182
8.3	General Characteristics of Focusing Collector Systems	186
8.4	Optical Losses; $\rho$ and $\tau\alpha$	190
8.5	Optical Losses; $\gamma$	191
8.6	Thermal Performance of Focusing Collectors	199
8.7	Heat Capacity Effects	204
8.8	Experimental Performance of a Focusing Collector	205
8.9	Collector Optimization for Maximum Energy Delivery	208
8.10	Special Geometries	209
8.11	Materials and Construction of Reflectors	210
CHAPTER 9. Energy Storage		215
9.1	Process Loads and Solar Collector Outputs	216
9.2	Energy Storage in Solar Process Systems	216
9.3	Water Storage	219
9.4	Packed Bed Exchanger Storage	227
9.5	Phase-Change Energy Storage	231
9.6	Capacities of Storage Media	235
9.7	Storage System Capacity	236
9.8	Alternative Storage Methods	237
9.9	Summary of Storage Considerations	238
CHAPTER 10. Solar Process Models		240
10.1	Component Models	241
10.2	System Models	242
CHAPTER 11. Solar Water Heating		252
11.1	Water Heater Systems	252
11.2	Collectors and Storage Tanks	253
11.3	Loads and Sizing of Systems	256
11.4	Auxiliary Energy	256
11.5	Flow Distribution in Collectors	261
11.6	Performance of Natural Circulation Systems	264

11.7	Freezing Temperatures	266
11.8	Two Special Purpose Designs	268
11.9	Results of Simulation of a Water Heating System	268
CHAPTER 12. Solar Heating		271
12.1	Survey of Solar Heating Experiments	272
12.2	Solar Heating Systems	273
12.3	The Denver Solar House	276
12.4	MIT House IV	280
12.5	Solar Heating Economics	282
12.6	Some Architectural Considerations	289
12.7	Modeling of Solar Heating Systems	291
12.8	Performance and Costs Calculations of a Solar Heating System	293
CHAPTER 13. Solar Cooling		305
13.1	Review of Solar Absorption Cooling	306
13.2	Performance of a Solar Operated Absorption Cooler	309
13.3	Economics of Solar Heating and Cooling	312
13.4	Combined Solar Heating and Cooling Systems	315
13.5	Modeling of Absorption Coolers	316
13.6	Modeling of Heating and Cooling Systems	318
13.7	Performance and Cost Calculations of a Solar Heating and Cooling System	319
CHAPTER 14. Additional Methods for Solar Heating/Cooling		332
14.1	Collector-Storage Wall Systems	332
14.2	Collector-Radiator-Storage System	334
14.3	Collector-Radiator-Heat Pump Systems	334
14.4	Solar Energy-Heat Pump Systems	338
14.5	Thermal and Photovoltaic Systems	338
14.6	Open-Cycle Cooling Systems	339
CHAPTER 15. Notes on Solar Ponds, Solar Power, and Solar Distillation		346
15.1	Solar Ponds	346
15.2	Solar Thermal Power	346
15.3	Solar Distillation	347
APPENDICES		
Appendix A	Problems	350
Appendix B	Nomenclature	367
Appendix C	The International System of Units [SI]	371

INDEX	375
Subject	375
Author	384