

CONTENTS

SOLAR ENERGY 1

1. THE SUN	3
1.1. Composition of the Sun	4
1.2. Atmosphere of the Sun.....	5
1.3. Origin of the solar energy	7
1.4. Extraterrestrial solar radiation	9
1.5. Terrestrial solar radiation	10
1.6. Solar radiation measurements	17
1.6.1. Measurement of sunshine duration. Heliographs.	18
1.6.2. Measurement of direct solar radiation intensity. Pyrheliometers. .	19
1.6.3. Measurement of intensity of global and diffuse solar radiation. Piranometers.....	20
REFERENCES	23

PHOTOTHERMAL SOLAR ENERGY CONVERSION..... 25

1. LOW TEMPERATURE SOLAR ENERGY CONVERSION	27
1.1. Flat plate collectors.....	27
1.1.1. Flat plate collectors with fluid.....	27
1.1.2. Flat plate collectors with air	30
1.2. Current efficiency of flat plate collector.....	31
1.3. Daily efficiency of flat plate collector	34
1.4. Solar boiler.....	35
1.5. Solar system with natural water circulation.....	35
1.6. Solar system with forced water circulation.....	36
1.7. Solar pools	37
2. MIDDLE TEMPERATURE SOLAR ENERGY CONVERSION	38
2.1. Vacuum collectors with concentrators	38
2.2. Solar furnace	41
3. HIGH TEMPERATURE SOLAR ENERGY CONVERSION	43
3.1. Heliostats	44
3.2. High temperature solar ovens	45
3.3. Concentrating solar power plants (CSP).....	46
3.3.1. Parabolic trough power plants	46
3.3.2. Solar tower power plants	47
3.3.3. Parabolic dish power plants	48
3.3.4. Power plants with Fresnel reflectors	49
3.3.5. Comparison of different types of CSP plants	50

3.4. Examples.....	51
3.4.1. CSP plants in the world	51
3.4.2. Parabolic trough power plants	52
3.4.3. Solar tower power plants	55
3.4.4. Parabolic dish power plants	61
3.4.5. Power plants with Fresnel reflectors	62
REFERENCES	65

PHOTOVOLTAIC SOLAR ENERGY CONVERSION 69

1. SOLAR CELLS	71
1.1. Output parameters of solar cells	74
1.2. Factors influencing solar cells efficiency	76
1.3. Types of solar cells.....	77
1.3.1. Monocrystalline silicon solar cells	77
1.3.2. Polycrystalline silicon solar cells	80
1.3.3. Amorphous silicon solar cells.....	82
1.3.4. GaAs solar cells	86
1.3.5. CdTe solar cells	87
1.3.6. CIS solar cells.....	88
1.3.7. Cu ₂ S/CdS solar cells	90
1.4. Solar cells application.....	90
1.4.1. Stand-alone photovoltaic systems	90
1.4.2. Components of the stand-alone photovoltaic solar systems	92
1.4.3. Determining characteristics of the stand-alone photovoltaic solar system	94
1.4.4. Grid connected photovoltaic solar system.....	96
2. PV SOLAR POWER PLANTS	97
2.1. Fixed PV solar power plants	98
2.2. One-axis tracking PV solar power plant	99
2.3. Dual-axis tracking PV solar power plant	100
2.4. Review of the installed PV solar power plants	101
2.5. Softwares for the calculation of the PV solar power plants energy efficiency	107
2.5.1. PVGIS.....	108
2.5.2. HOMER software	110
2.5.3. SWERA	113
2.5.4. RETScreen.....	113
2.6. Solar databases.....	114
2.6.1. NASA–Surface meteorology and solar energy database.....	114
2.6.2. PVGIS solar database	115

3. PHOTOVOLTAIC/THERMAL SOLAR COLLECTORS	116
3.1. Introduction.....	116
3.2. Design and operation of PV/T collectors.....	118
3.3. The effect of temperature to PV cell electrical efficiency	122
3.4. The effect of illumination to PV cell electrical efficiency	124
3.5. Design principles of flat plate PV/T collectors.....	125
3.6. Concentrating PV/T collectors.....	128
3.6.1. Design and cooling modes of concentrating photovoltaics	128
3.6.2. The booster diffuse reflector concept	130
3.6.3 PV/T collector test results.....	131
3.6.4. Environmental aspects of PV/T collectors	134
3.7. PV/T collector performance.....	134
3.7.1. PV/T collector analysis principles	134
3.7.2. Flat plate PV/T collectors with liquid heat recovery	135
3.7.3. Flat plate PV/T collectors with air heat recovery	137
3.7.4. Pressure drop	138
3.7.5. PV/T–air collectors with forced air flow	139
3.7.6. PV/T–air collectors with natural air flow	139
3.8. PV/T collector performance improvements.....	140
3.8.1. Modified PV/T collectors	140
3.8.2. Modified PV/T collectors with improvements	141
3.8.3. Hybrid PV/T system design considerations.....	141
3.9. The PVT/DUAL system concept	142
3.10. Application of PV/T collectors	143
3.10.1. PV/T collectors in the built environment	143
3.10.2. Thermosiphonic PV/T solar water heaters	145
3.10.3. PV/T-TC combined systems	145
3.10.4. Fresnel/PVT system for solar control of buildings.....	146
3.10.5. Other CPVT collector designs	148
3.11. PV/T collectors in industry and agriculture	149
3.11.1. PV/T collectors for the industry.....	149
3.11.2. PV/T collectors in the agriculture.....	151
3.11.3. PV/T collectors combined with other renewable energy sources ..	152
3.12. Conclusions.....	152
REFERENCES	153

SOLAR ARCHITECTURE..... 161

1. PASSIVE SOLAR ARCHITECTURE	163
1.1. Building orientation.....	163
1.2. Shades.....	164
1.3. Windows	164
1.4. Thermal curtains.....	165
1.5. Wall and furniture colors.....	165
1.6. Trombe wall	166

1.7. Active massive wall	169
1.8. Water wall	170
1.9. Phase changing heat storages.....	173
1.10. Glass veranda.....	174
1.11. Floor heat storage.....	175
2. BUILDING INTEGRATION OF SOLAR ENERGY SYSTEMS	175
2.1. Introduction.....	175
2.2. Building integration aspects.....	177
2.3. Solar energy systems for building integration	180
2.4. Building integrated photovoltaics (BIPV)	182
2.4.1. Efficiency aspects of BIPVs	183
2.4.2. The BIPVT concept	185
2.4.3. Other BIPV aspects	187
2.5. Building integrated solar thermal systems (BISTS)	190
2.5.1. Definitions and design aspects of BISTS	190
2.5.2. Passive solar systems.....	195
2.5.3. Architectural integration of solar thermal systems	197
2.5.4. Aesthetical possibilities	199
2.5.5. Unglazed solar thermal collectors	201
2.5.6. Environmental benefits of using BISTS	203
2.6. Hybrid photovoltaic/thermal solar systems	204
2.7. Building integrated concentrating solar energy systems	207
2.7.1. Concentrators for solar thermal collectors and photovoltaics	207
2.7.2. Operational and architectural aspects for BICPVT systems.....	209
REFERENCES	210

SOLAR ENERGY MATERIALS CHARACTERIZATION..... 215

1. INTERACTIONS OF ELECTRONS WITH SPECIMENS.....	217
2. METHODS AND DEVICES.....	221
2.1. Scanning electron microscopy	221
2.2. Electron microprobe	227
2.3. Auger electron spectroscopy	232
2.4. Spectrophotometer with Ulbricht sphere	234
2.5. Emissometer.....	235
2.6. Elipsometer	236
2.7. Solar radiation simulator.....	237
REFERENCES	239

SOLAR ENERGY IN SERBIA 241

1. GENERAL INFORMATION ABOUT SOLAR ENERGY IN SERBIA.....	243
1.1. Geographic position	243
1.2. Climate in Serbia	244
1.3. Solar radiation in Serbia	247
1.4. Air pollution in Serbia.....	249
1.5. Renewable energy policy in Serbia.....	251
1.6. Current state of solar energy use in Serbia	257
1.6.1. Low temperature solar energy conversion.....	258
1.6.2. Medium temperature solar energy conversion	265
1.6.3. High temperature solar energy conversion	265
1.6.4. Photovoltaic solar energy conversion.....	266
1.6.5. PV solar power plants in Serbia	268
1.6.6. Other applications of solar cells	285
1.6.7. Solar architecture.....	285
1.7. Perspectives of the solar energy use in Serbia.....	286
1.8. Solar Energy Laboratory at the Faculty of Sciences and Mathematics in Nis	287
1.9. Solar Energy Laboratory at the Technical Faculty <i>Mihajlo Pupin</i> in Zrenjanin	292
2. RESULTS OBTAINED IN SOLAR ENERGY LABORATORY AT THE FACULTY OF SCIENCE AND MATHEMATICS, UNIVERSITY OF NIS	295
2.1. Optical and microstructural properties of anodically oxidized aluminium.....	295
2.2. Optical properties of spectrally selective anodically coated electrolytically colored aluminium surfaces	304
2.3. Amorphous silicon solar cells on anodically oxidized aluminium substrate.....	315
2.4. Influence of physical characteristics of flat aluminum concentrators on energy efficiency of PV/thermal collector	320
2.5. Optimal design of orientation of PV/T collector with reflectors.....	330
2.6. Comparison and assessment of electricity generation capacity for different types of PV solar plants of 1 MW in Sokobanja.....	343
2.7. A review of concentrating solar power plants in the world and their potential use in Serbia	350
2.8. Assessment and potential use of concentrating solar power plants in Serbia.....	352
2.9. Possibility of electricity generation using PV solar plants in Serbia	356
2.10. Simulation of PV systems electricity generation using Homer software in specific locations in Serbia.....	364
2.11. Assessment of the possibilities of building integrated PV systems of 1 kW electricity generation in some spa resorts in Serbia	376
2.12. Performance analysis of a grid connected PV solar plant in Nis, Republic of Serbia	393
2.13. A practical field study of performances of solar modules at various positions in Serbia	408
REFERENCES	420

SOLAR ENERGY IN GREECE 425

1. GENERAL INFORMATION ABOUT SOLAR ENERGY IN GREECE ..	427
1.1. Geographical position	427
1.2. Climate in Greece	429
1.3. Solar radiation in Greece	432
1.4. Renewable energy policy in Greece	433
1.5. Current state of solar energy use in Greece	437
1.6. Perspectives of solar energy use in Greece.....	441
1.7. Solar Energy Laboratory at the Department of Physics, University of Patras.....	443
1.7.1. The University of Patras.....	443
1.7.2. Solar Energy Laboratory at the Department of Physics	444
2. RESULTS OBTAINED IN SOLAR ENERGY LABORATORY OF PHYSICS DEPARTMENT AT THE UNIVERSITY OF PATRAS	451
2.1. Hybrid Photovoltaic/Thermal solar systems.....	451
2.1.1. Introduction	451
2.1.2. Hybrid system design considerations	452
2.1.3. Experimental models	454
2.1.4. Experimental study	457
2.1.5. Results and discussion	461
2.1.6. Experiments with the diffuse reflector	463
2.1.7. Results from comparison tests	469
2.1.8. Conclusions	474
2.2. Improved PV/T solar collectors with heat extraction by forced or natural air circulation	475
2.2.1. Introduction	475
2.2.2. Experimental systems	477
2.2.3. PV/T energy performance.....	479
2.2.4. Experimental results	480
2.2.5. Discussion.....	485
2.2.6. Conclusions	487
2.3. Air-cooled PV/T solar collectors with low cost performance improvements	488
2.3.1. Introduction	488
2.3.2. Experimental study and model development.....	490
2.3.3. Pressure drop	500
2.3.4. Validation results	502
2.3.5. PVT/AIR collector case studies.....	506
2.3.6. Discussion.....	511
2.3.7. Conclusions	513
2.4. Aspects and improvements of hybrid photovoltaic/thermal solar energy systems.....	514
2.4.1. Introduction	514
2.4.2. Application aspects for PV/T systems	516
2.4.3. PV/T design improvements	519

2.4.4. PVT/Dual experimental study	523
2.4.5. Discussion.....	533
2.4.6. Conclusions	535
2.5. Performance, cost and life cycle assessment study of hybrid PVT/AIR solar systems	536
2.5.1. Introduction	536
2.5.2. Experimental models	537
2.5.3. Experimental results	538
2.5.4. LCA methodology	541
2.5.5. Conclusions	545
2.6. Solar collectors with colored absorbers	545
2.6.1. Introduction	545
2.6.2. Experimental models	547
2.6.3. Experimental study and results.....	549
2.6.4. Theoretical results and discussion	554
2.6.5. Conclusions	561
2.7. The Fresnel lens concept for solar control of buildings.....	561
2.7.1. Introduction	561
2.7.2. The Fresnel lens concept	564
2.7.3. Experimental study	568
2.7.4. Energy conversion results.....	577
2.7.5. Discussion on the solar control of buildings	579
2.7.6. Conclusions	580
2.8. New designs of building integrated solar energy systems	581
2.8.1. Introduction	581
2.8.2 System design aspects	583
2.8.3 Suggested solar energy systems	584
2.8.4 Conclusions	590
2.9. ICS solar systems with two water tanks	591
2.9.1. Introduction	591
2.9.2. Design principles	592
2.9.3. Experimental models	594
2.9.4. Experimental study.....	599
2.9.5. Discussion of the results	605
2.9.6. Conclusions	606
2.10. Aspects of PV/T solar system application for ventilation needs in greenhouses	607
2.10.1. Introduction	607
2.10.2. Greenhouse cooling requirements	608
2.10.3. Hybrid PV/T systems.....	608
2.10.4. The PV/T concept for greenhouse ventilation.....	610
2.10.5. Case study.....	612
2.10.6. Conclusions	614
REFERENCES	614

SOLAR ENERGY IN THE REPUBLIC OF SRPSKA.....619

1. GENERAL INFORMATION ABOUT SOLAR ENERGY IN THE REPUBLIC OF SRPSKA.....	621
1.1. Geographical position	621
1.2. Climate in the Republic of Srpska	622
1.3. Solar radiation in the Republic of Srpska	624
1.4. Renewable energy policy in Bosnia and Herzegovina	626
1.5. Current state of solar energy use in the Republic of Srpska	629
1.5.1. Thermal solar energy conversion.....	629
1.5.2. PV solar power plants in the Republic of Srpska	630
1.6. Perspectives of solar energy use in the Republic of Srpska.....	634
1.7. Solar Energy Laboratory at the Academy of Sciences and Arts in the Republic of Srpska	635
2. RESULTS OBTAINED IN SOLAR ENERGY LABORATORY AT THE ACADEMY OF SCIENCES AND ARTS IN THE REPUBLIC OF SRPSKA .	637
2.1. Assessment and potential use of concentrating solar power plants in the Republic of Srpska	637
2.2. Assessments and perspectives of PV solar power engineering in the Republic of Srpska (Bosnia and Herzegovina)	641
2.3. Energy efficiency of PV solar plant in real climate conditions in Banja Luka	649
2.4. Investigation of the polycrystalline solar modules energy efficiency in relation to their geographical orientation and tilt angle	658
2.5. Articles of physical characteristics of thin film materials.....	667
REFERENCES	673

AUTHORS REFERENCES CITED IN THIS BOOK.....677