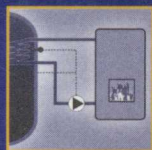
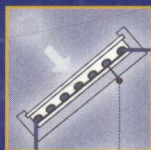
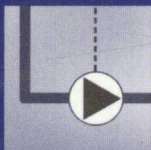
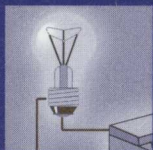
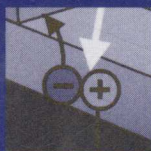
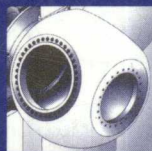
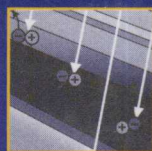


# understanding renewable energy systems



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# Understanding Renewable Energy Systems

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Volker Quaschning



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# Understanding Renewable Energy Systems

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# List of Acronyms and Abbreviations

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AC	alternating current
AM	air mass
BTU	British thermal unit
CB	conduction band
CET	Central European Time
CFCs	chlorofluorocarbons
CHP	combined heat and power
CIS	copper indium diselenide
COP	coefficient of performance
CPI	consumer price index
CVD	chemical vapour deposition
DC	direct current
EG-Si	electronic-grade silicon
EPDM	ethylene propylene diene monomer
ESTIF	European Solar Thermal Industry Federation
EVA	ethylene vinyl acetate,
FB	forbidden band
FF	fill factor
GMT	Greenwich Mean Time
GTO	gate turn off
GUT	Greenwich Universal Time
HDR	hot dry rock method
IC	integrated circuit
ICS	integral collector storage
IEA	International Energy Agency
IGBT	insulated gate bipolar transistors
IPCC	Intergovernmental Panel on Climate Change
IR	infrared reflecting
kg ce	kg coal equivalent
kg oe	kg oil equivalent
LCV	lower calorific value
LEC	levelled electricity cost
LHC	levelled heat cost
MCA	maximum credible accident
MCFC	molten carbonate fuel cell
MET	Mean European Time
MG-Si	metallurgical grade silicon
MIS	metal-insulator-semiconductor
MLT	Mean Local Time

MOSFET	metal oxide semiconductor field effect transistor
MPP	maximum power point
NaS	sodium–sulphur
NiCd	nickel–cadmium
NiMH	nickel–metal hydride
NPV	net present value
PAFC	phosphoric acid fuel cell
PE	polyethylene
PP	polypropylene
ppm	parts per million
ppmv	parts per million by volume
PR	performance ratio
PR	progress ratio (Chapter 6)
PST	Pacific Standard Time
PV	photovoltaic
PWM	pulse-width modulation
R&D	research and development
rms	root mean square
SEGS	solar electric generation system
SOC	state of charge
SOFC	solid oxide fuel cell
SOG-Si	solar grade silicon
sr	steradian
STC	standard test conditions
TIM	transparent insulation material
UCV	upper calorific value
UNEP	United Nations Environmental Programme
UNFCCC	United Nations Framework Convention on Climate Change
VB	valence band
VDEW	Vereinigung Deutscher Elektrizitätswerke
VDI	Verein Deutscher Ingenieure
WMO	World Meteorological Organisation

# Preface

---

The destruction of the environment and global warming are among the problems first mentioned in many public opinion polls that ask what are the major problems to be solved in this century. Today's energy supply is largely responsible for the anthropogenic greenhouse effect, acid rain and other negative impacts on health and the environment. The current trend is clearly not sustainable, especially given the enormous demand for energy predicted for the future. Several energy sources, however, offer the opportunity to cover our energy demand sustainably, i.e. with almost no negative influence on health and nature. These are also called renewable energy systems, because the 'fuel' is replenished by nature.

This textbook is based on the German book *Regenerative Energiesysteme*, which was first published in 1998 and became a standard text used at German universities in courses on renewable energy. Two editions have sold out and the third edition came out in 2003.

The book is aimed mainly at students, engineers, researchers and others with technical interests wanting to obtain a basic knowledge of renewable energy production. It describes the most important technical systems for using renewable energy sources, and introduces important calculation and simulation methods for these. The main focus is on technologies with high development potentials such as solar thermal systems, photovoltaics and wind power.

When describing renewable energy subjects, one has to consider technical descriptions as well as the impact on today's energy supply or sociopolitical backgrounds. A compromise between socioeconomic and technical issues must be found when dealing with energy matters. A textbook with technical focus has the obligation to describe technologies in an objective manner. However, the author's subjective influence can never be avoided entirely. The choice of contents, methods of data presentation and even the subjects left out of the book are already based on opinions.

Therefore, this book consciously renounces separation of the technological aspects from any consequences of using the technologies, or from sociopolitical aspects. The intention is to emphasize that engineers must bear in mind the potential negative impacts of the use of developed technologies. Otherwise they must accept the heavy responsibility of allowing those impacts to occur.

Those in engineering circles are often of the opinion that the development of technology itself cannot have negative consequences. It is the use of a technology that would create such consequences. However, it is irresponsible to search for technical innovations only for the sake of improving technology. The consequences of many new or even well established technologies are very

difficult to estimate in many cases. Therefore, all who are involved in the development, production and application of a technology are responsible for predicting consequences critically and warning of possible dangers in time. With the aim of acknowledging this responsibility, this book always tries to point out negative consequences besides description of facts.

From my experience as a professor in the education sector, I know that the majority of people who are interested in renewable energy technologies deals intensively with the consequences of the conventional energy supply. A linking of technical with sociopolitical contents is often desired implicitly. Therefore, this textbook does not only describe technological aspects, but also deals consciously with problems of the energy industry in Chapters 1 and 6. Here, great importance was attached to substantiating all statements with objective and up-to-date facts. This allows all readers to form their own opinion.

Interesting discussions while writing this book and the very positive feedback on the German version of this book were especially motivating for me. They have shown that problems that go beyond purely technical questions are seen as very important. These problems are often ignored because they question our way of life. Solutions are difficult but not impossible to find. Constructive discussions are the first step. I hope this book can provide a contribution to such a discussion.

*Volker Quaschning*  
*Berlin, Summer 2004*



# Contents

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<i>List of Figures and Tables</i>	<i>vii</i>
<i>List of Acronyms and Abbreviations</i>	<i>xvi</i>
<i>Preface</i>	<i>xviii</i>
<b>1 Energy, Climate Change and Renewable Energy Sources</b>	<b>1</b>
The Expression 'Energy'	1
Evolution of World Energy Demand	6
Reserves of Fossil Energy Sources	8
Greenhouse Effect	10
Nuclear Power versus the Greenhouse Effect	16
Renewable Energies	19
Global Use of Renewable Energy Sources	35
Future Energy Demand and Climatic Protection	39
<b>2 Solar Radiation</b>	<b>44</b>
Introduction	44
The Sun as a Fusion Reactor	44
Solar Irradiance on the Surface of the Earth	48
Irradiance on a Horizontal Plane	52
Calculation of the Sun's Position	55
Calculation of the Solar Angle of Incidence	59
Irradiance on Tilted Surfaces	60
Calculation of Shading Losses	66
<b>3 Solar Thermal Water Heating</b>	<b>77</b>
Introduction	77
Solar Thermal Systems for Water Heating	79
Solar Collectors	85
Pipes	97
Thermal Storage	102
Heat Demand and Solar Fraction	111
<b>4 Photovoltaics</b>	<b>115</b>
Introduction	115
Operation of Solar Cells	116
Production of Solar Cells and Solar Modules	127
Electrical Description of Solar Cells	130

	Electrical Description of Photovoltaic Modules	141
	Solar Generator with Load	148
	Electricity Storage	157
	Inverters	172
<b>5</b>	<b>Wind Power</b>	<b>181</b>
	Introduction	181
	The Wind	182
	Utilization of Wind Energy	188
	Wind Turbine Design	196
	Electrical Machines	204
	Electrical System Concepts	225
	Mains Operation	232
<b>6</b>	<b>Economics</b>	<b>235</b>
	Introduction	235
	Classical Economic Calculations	236
	External Costs	248
	Critical View of Economic Calculations	254
<b>7</b>	<b>Simulations and the CD-ROM of the Book</b>	<b>257</b>
	Introduction to Computer Simulations	257
	The CD-ROM of the Book	258
	<i>Appendix</i>	261
	<i>References</i>	264
	<i>Index</i>	000

# List of Figures and Tables

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## FIGURES

1.1	Prices for Water Heating	4
1.2	Energy Conversion Chain and Losses for Water Heating with a Gas Cooker	5
1.3	Energy Conversion Chain and Losses for Water Heating with an Electric Cooker	6
1.4	Evolution of Annual Crude Oil Production	7
1.5	World Primary Energy Demand by Region in 2001	8
1.6	Origin of the Anthropogenic (Human-induced) Greenhouse Effect	11
1.7	Annual per capita Carbon Dioxide Emissions from Fuel Combustion for Different Countries in 2001	14
1.8	Nuclear Power's Share of Electricity Generation in 2000	17
1.9	Energy Cubes: the Annual Solar Irradiation Exceeds Several Times the Total Global Energy Demand and All Fossil Energy Reserves	22
1.10	Principle of a Parabolic Trough Solar Power Plant	24
1.11	Demonstration Solar Thermal Tower Power Plant in Spain	24
1.12	Principle of a Dish-Stirling System	25
1.13	Principle of the Solar Chimney Power Plant	26
1.14	Principle of the Global Water Cycle	28
1.15	Principle of a Hydro-electric Power Plant	29
1.16	Pumped-storage Hydro-electric Power Plant in Southern Spain near Malaga.	30
1.17	Itaipu Hydro-electric Power Plant (Photo: Itaipu Binacional)	31
1.18	Biomass Power Plant Using Residues of Olive Oil Production in Southern Spain (Photos: Markus Maier/Steffen Ulmer)	33
1.19	Principle of a Compression Heat Pump	34
2.1	Fusion of Four Hydrogen Nuclei to Form One Helium Nucleus (Alpha Particle)	45
2.2	The Radiant Power through the Surface of a Sphere with Radius $r_{SE}$ is the Same as through the Surface of the Sun.	47
2.3	Spectrum of Sunlight	49
2.4	Sun Height at Solar Noon and Air Mass (AM) Values for Various Dates in Berlin and Cairo	50
2.5	Global Irradiance throughout the Day in Karlsruhe (Germany) for 2 July and 22 and 28 December 1991	51
2.6	Sunlight Passing Through the Atmosphere	53

2.7	Daily Direct and Diffuse Irradiation in Berlin	54
2.8	Daily Direct and Diffuse Irradiation in Cairo	54
2.9	Diffuse Irradiance Component as a Function of $k_T$ and $\gamma_s$	55
2.10	Definitions of the Angles Describing the Position of the Sun Used in this Book	56
2.11	Solar Position Diagram for Berlin, Germany (52.5°N)	58
2.12	Solar Position Diagram for Cairo, Egypt (30.1°N)	59
2.13	Definition of the Solar Angle of Incidence on a Tilted Surface	60
2.14	Irradiance on a Horizontal Area $A_{hor}$ and an Area $A_s$ Perpendicular to the Sunlight	61
2.15	Irradiance on Horizontal and Two-axis Tracked Surfaces for Cloudless Days at a Site at 50° Latitude	65
2.16	Annual Irradiation on Various Inclined Surfaces in Berlin (52.5°N)	66
2.17	Annual Irradiation on Various Inclined Surfaces in Cairo (30.1°N)	67
2.18	Definition of the Obstacle Height Angle and Obstacle Azimuth Using a Freely Chosen Point of Reference	68
2.19	Estimation of Object Azimuth and Height Angles Using a Simple Optical Instrument	68
2.20	Surroundings Seen through a Screen with Angular Grid	69
2.21	Solar Position Diagram of Berlin with an Approximation of the Surroundings	70
2.22	Shading Test for Two Different Positions of the Sun A and B	70
2.23	Two Points, the Horizontal Meridian and Two Polar Meridians Define the Polygon Area	71
2.24	Dimensions of Solar Energy Systems and Support Structure Rows	73
2.25	Shading Angle $\alpha$ as a Function of the Degree of Ground Utilization $u$ and the Surface Tilt Angle $\gamma_t$	74
2.26	Relative Shading Losses $s$ as a Function of the Shading Angle $\alpha$ and Surface Tilt Angle $\gamma_t$ in Berlin (52.5°N)	75
3.1	Heat Transfer through $n$ Layers with the Same Surface Area $A$	79
3.2	Principle of Solar Thermal Swimming Pool Heating	81
3.3	Schematic of a Thermosyphon System	83
3.4	Schematic of a Double-Cycle System with Forced Circulation	85
3.5	Cross-section through an Integral Collector Storage System	87
3.6	Processes in a Flat-plate Collector	88
3.7	Energy Conversion in the Solar Collector and Possible Losses	89
3.8	Processes at the Collector Front Glass Cover	89
3.9	Various Designs of Solar Absorber	91
3.10	Losses at Absorber Surfaces with Different Types of Coating	91
3.11	Spectra of Black Bodies at 5777 K and 350 K and the Absorptance of Selective and Non-selective Absorbers	92
3.12	Assembly and Function of the Evacuated Tube Collector with Heat Pipe	93
3.13	Photo of the Connections of the Evacuated Tubes to the Solar Cycle	94

3.14 Collector Efficiencies $\eta_C$ at Different Irradiances $E$ and Temperature Differences $\Delta\theta$	97
3.15 Cylindrical Hot Water Tank with Spherical Ends	105
3.16 Storage Temperature $\theta_s$ for a 300-litre Storage Tank without Loading or Unloading	107
3.17 Collector Systems with Two Storage Tanks	108
3.18 Energy Balance of a Swimming Pool	108
3.19 Solar Fraction as a Function of the Collector Surface	113
4.1 Roof-integrated Photovoltaic System	116
4.2 Energy States of Electrons in Atoms, Molecules and Solids	119
4.3 Energy Bands of Conductors, Semiconductors and Isolators	119
4.4 The Lifting of Electrons from the Valence Band to the Conduction Band Caused by Light Energy in a Semiconductor	120
4.5 Crystal Structure of Silicon (left), Intrinsic Conduction due to Defect Electron in the Crystal Lattice (right)	121
4.6 Defect Conduction for n-type and p-type Doped Silicon	123
4.7 Space Charge Region Formation at a p-n Junction by Diffusion of Electrons and Holes	124
4.8 Solar Cell Principle with Energy Band Model	125
4.9 Processes in an Irradiated Solar Cell	126
4.10 Spectral Response of a Solar Cell	126
4.11 Solar Cell Structure and Front View of a Crystalline Silicon Solar Cell	129
4.12 Structure of an Amorphous Silicon Solar Module	130
4.13 Simple Equivalent Circuit of a Solar Cell	131
4.14 Influence of the Irradiance $E$ on the I-V Characteristics of a Solar Cell	131
4.15 Extended Equivalent Circuit of a Solar Cell (One-diode Model)	132
4.16 Influence of the Series Resistance $R_s$ on the I-V Characteristics of a Solar Cell	133
4.17 Influence of the Parallel Resistance $R_p$ on the I-V Characteristics of a Solar Cell	133
4.18 Two-diode Model of a Solar Cell	134
4.19 Two-diode Equivalent Circuit with Second Current Source to Describe the Solar Cell Breakdown at Negative Voltages	136
4.20 I-V Characteristics of a Polycrystalline Solar Cell over the Full Voltage Range	136
4.21 I-V and P-V Solar Cell Characteristics with Maximum Power Point (MPP)	138
4.22 Temperature Dependence of Solar Cell Characteristics	140
4.23 Series Connection of Photovoltaic Solar Cells	142
4.24 Construction of Module Characteristics with 36 Cells	142
4.25 Construction of Module Characteristics with a 75 per cent Shaded Cell	144
4.26 Integration of Bypass Diodes across Single Cells or Cell Strings	145

4.27 Simulation of Module Characteristics with Bypass Diodes across Different Numbers of Cells	145
4.28 P-V Characteristic of a Module with 36 Cells and Two Bypass Diodes	146
4.29 Parallel Connection of $n$ Solar Cells	147
4.30 Solar Generator with Resistive Load	148
4.31 Solar Module with Resistive Load at Different Operating Conditions	149
4.32 Solar Generator with Load and DC–DC Converter	150
4.33 Solar Module with Constant Voltage Load for Three Different Operating Conditions	150
4.34 Circuit of a Buck Converter with Resistive Load	151
4.35 Current $i_2$ and Voltage $v_D$ for a Buck Converter	152
4.36 Buck Converter with Capacitors	152
4.37 Boost Converter Circuit	154
4.38 Buck–Boost Converter Circuit	154
4.39 Flyback Converter Circuit	155
4.40 Structure of MPP Trackers	157
4.41 Charging and Discharging a Lead–Acid Battery	159
4.42 Usable Capacity Related to $C_{100} = 100 \text{ A h}$ of a Lead–Acid Battery as a Function of the Discharge Current and Temperature	160
4.43 Battery Voltage as a Function of Discharge Time and Discharge Current	162
4.44 Gretsche Equivalent Circuit of a Lead–Acid Battery	163
4.45 Simple Photovoltaic System with Battery Storage	166
4.46 Operating Points of a Solar Module Connected to Battery Storage with a Blocking Diode and $0.1 \Omega$ Cable Resistance without Load	167
4.47 Photovoltaic Battery System with Series Charge Controller	168
4.48 Photovoltaic Battery System with Parallel Charge Controller	168
4.49 Principle of Hydrogen Electrolysis with Alkaline Electrolyte	169
4.50 Principle of the Fuel Cell with Acid Electrolyte	170
4.51 Photograph of a Fuel Cell Stack Prototype	171
4.52 Thyristor Symbol	172
4.53 Two-pulse Bridge Connection (B2)	173
4.54 Idealized Current of a Half-controlled B2 Bridge Connection	174
4.55 Construction of a Square-wave Oscillation from Different Sinusoidal Harmonics	175
4.56 Six-pulse Bridge Inverter (B6)	176
4.57 Voltage using Pulse-width Modulation (PWM)	177
4.58 Efficiency over a Range of Relative Photovoltaic Generator Powers	178
4.59 Photovoltaic System with Parallel Strings and Central Inverter	179
4.60 Photovoltaic Generator with String Inverters (left) and Module Inverters (right)	179
5.1 Wind Speed Distribution for Karlsruhe in Inland Germany in 1991/1992	184

5.2	Rayleigh Distributions for Different Mean Wind Speeds $v$	185
5.3	Common Expressions for the Description of the Direction of the Wind	186
5.4	Idealized Change of Wind Speed at a Wind Turbine	190
5.5	Drag Coefficients for Various Shapes	191
5.6	Model of Cup Anemometer for the Calculation of Power	192
5.7	Apparent Wind Speed $v_A$ Resulting from the Real Wind Speed $v_w$ and Rotor Motion	193
5.8	Ratio of the Forces for a Lift Device	194
5.9	Power Coefficient $c_p$ as a Function of the Tip Speed Ratio $\lambda$ for the Vestas V44-600-kW Wind Generator	195
5.10	Power Coefficients and Approximations using Third-degree Polynomials	196
5.11	Rotors with Vertical Axes	197
5.12	Section through the Stall-controlled TW600 Wind Generator	199
5.13	Generator Active Power and Power Coefficient against Wind Speed for the 500-kW Enercon E-40 Wind Generator	201
5.14	Stall Effect at Higher Wind Speeds	202
5.15	Rotor Blade Positions for Different Wind Speeds for a Pitch-controlled System	203
5.16	Current and Voltage as a Function of Time and Vector Diagram of the Amplitudes $i$ and $v$ ( $\varphi = \pi/4$ )	205
5.17	Series Connection of Resistance and Inductance with Vector Diagram	207
5.18	Magnetic Fields Produced by an Electric Current in a Wire and Coil	208
5.19	Cross-section through a Stator with Three Coils Staggered by $120^\circ$ for the Generation of a Rotating Field	209
5.20	Change in the Magnetic Field at Two Different Points in Time when Supplying Three Sinusoidal Currents that are Temporally Staggered by $120^\circ$	210
5.21	Three-phase Currents to Generate a Rotating Field	210
5.22	Principle of Star and Delta Connections	211
5.23	Cross-section through a Synchronous Machine	213
5.24	Simple Equivalent Circuit ( $R_1 = 0$ ) of a Cylindrical Rotor Machine for One Phase	215
5.25	Vector Diagrams of a Synchronous Machine with Cylindrical Rotor	215
5.26	Curve of the Torque of a Synchronous Machine with Cylindrical Rotor as a Function of the Load Angle $\vartheta$ and the Internal Voltage $V_p$	217
5.27	Ideal Transformer with Resistances and Reactances	219
5.28	Equivalent Circuit for One Phase of an Asynchronous Machine	220
5.29	Circle Diagram for the Estimation of the Stator Current According to Heyland and Ossanna	221

5.30 Simplified One-phase Equivalent Circuit for an Asynchronous Machine	222
5.31 Power Balance for an Asynchronous Generator	222
5.32 Speed-torque Characteristics for an Asynchronous Machine	225
5.33 Asynchronous Generator with Direct Mains Coupling	226
5.34 Torque Characteristics as a Function of Slip $s$ with Variation of the Rotor Resistance $R_R$	226
5.35 Operating Points for a Wind Turbine with Asynchronous Generator that is Directly Coupled to the Mains	227
5.36 Operating Points for a Wind Turbine with Two Asynchronous Generators with Different Speeds	228
5.37 Synchronous Generator with Direct Mains Coupling	229
5.38 Synchronous Generator with DC Link	229
5.39 Operating Points for a Variable-Speed Wind Generator with Power Limited by constant speed (1) or by a Converter (2)	230
5.40 Variable Speed Asynchronous Generator with Converter Cascade	231
5.41 Double-fed Asynchronous Generator with Direct Converter	231
6.1 Global Photovoltaic Module Production and End User Prices for Small Grid-connected Photovoltaic Systems in Germany	238
6.2 Specific Sale Prices for Wind Turbines in 1993 and 1999	239
6.3 Photovoltaic Module Prices in Germany, Japan and the USA	247
6.4 Crude Oil Prices Given in Actual Prices and Adjusted for Inflation and Exchange Rate	249
6.5 IEA Total Reported Government Energy Technology R&D Budgets for 1974 and 1998	251
7.1 Start Screen of the CD-ROM of the Book (Presentation with Mozilla Browser)	258
7.2 All Figures are Included and Can be Chosen Separately	259
7.3 Alphabetical Overview of all Software Programs on the CD-ROM	260

## TABLES

1.1 Conversion Factors for Energy	2
1.2 Prefixes	3
1.3 Primary Energy, Final Energy and Effective Energy	5
1.4 World Primary Energy Consumption Excluding Biomass and Others	8
1.5 Fossil Fuel Reserves	9
1.6 Uranium (U) Resources for 2001	10
1.7 Characteristics of Greenhouse Gases in the Atmosphere in 1998	12
1.8 Contribution of Hydro-electricity to the Net Electricity Generation in Different Countries	30
1.9 Technical Data of the Itaipu Hydro-electric Power Plant	31
1.10 Efficiencies for Biomass Production	32
1.11 Calorific Values of Various Biomass Fuels	32



1.12 Worldwide Total Installed Wind Generator Power in GW	36
1.13 Worldwide Total Installed Photovoltaic Power in GW	37
1.14 Worldwide Total Installed Hydro-electric Power in GW	37
1.15 Newly Installed Glazed Solar Thermal Collectors since 1990 and Total Glazed Collector Surface in Operation at the end of 2001 in 1000 m	37
1.16 Assumptions for the Evolution of World Population and Gross Domestic Product up to 2100 for Different IPCC Emission Scenarios	40
1.17 Assumptions for the Evolution of Primary Energy Demand and Ratio of Carbon Dioxide-Free Primary Energy by 2100 for Different IPCC Emission Scenarios	40
1.18 Various IPCC Emission Scenarios and Corresponding CO <sub>2</sub> Concentration in the Atmosphere, Average Annual Temperature Rise and Sea Level Rise by 2100	41
1.19 Specific CO <sub>2</sub> Emission Factors of Various Fuels	41
1.20 Emission Limitations or Reduction Commitment Pursuant to the Kyoto Protocol and Evolution by Signatories to the Protocol	42
2.1 Important Radiant Physical Quantities and Daylight Quantities	44
2.2 Data for the Sun and the Earth	45
2.3 Various Particle and Nuclide Masses	46
2.4 Reduction Influences at Different Sun Heights	49
2.5 Monthly Average Values in kWh/(m <sup>2</sup> day) of the Daily Global Irradiation	52
2.6 Monthly Average Daily Direct and Diffuse Irradiation in kWh/(m <sup>2</sup> day) in Berlin and Cairo	53
2.7 Annual Average Daily Direct and Diffuse Irradiation [kWh/ (m <sup>2</sup> day)]	53
2.8 Different Definitions of Solar Azimuth Angle	56
2.9 Latitude $\varphi$ and Longitude $\lambda$ of Selected Locations	58
2.10 Constants for Estimating $F_1$ and $F_2$ as a Function of $\varepsilon$	63
2.11 Albedo for Different Types of Surface	64
2.12 Ratio of the Global Irradiation on a Tilted Surface to a Horizontal Surface in Berlin and Cairo Calculated Using the Perez Diffuse Irradiance Model	66
2.13 Shading losses $s$ , Gain Factor $g$ and Overall Correction Factor $c$ for Point $P_0$ at Different Ground Utilizations and Tilt Angles Calculated for Berlin (52.5°N)	75
2.14 Average Relative Shading Losses $s$ and Overall Correction Factor $c$ for Points $P_0$ , $P_1$ and $P_2$ at Different Ground Utilizations and Tilt Angles Calculated for Berlin (52.5°N)	76
3.1 Thermodynamic Quantities for Thermal Calculations	77
3.2 Heat capacity $c$ for Some Materials at $\vartheta = 0\text{--}100^\circ\text{C}$	79
3.3 Thermal Conductivity of Various Materials	80
3.4 Heat Transition Coefficient $k$ and Total Energy Transition Coefficient ( $g$ -value) of Various Conventional Materials and Transparent Insulation Materials (TIMs)	86