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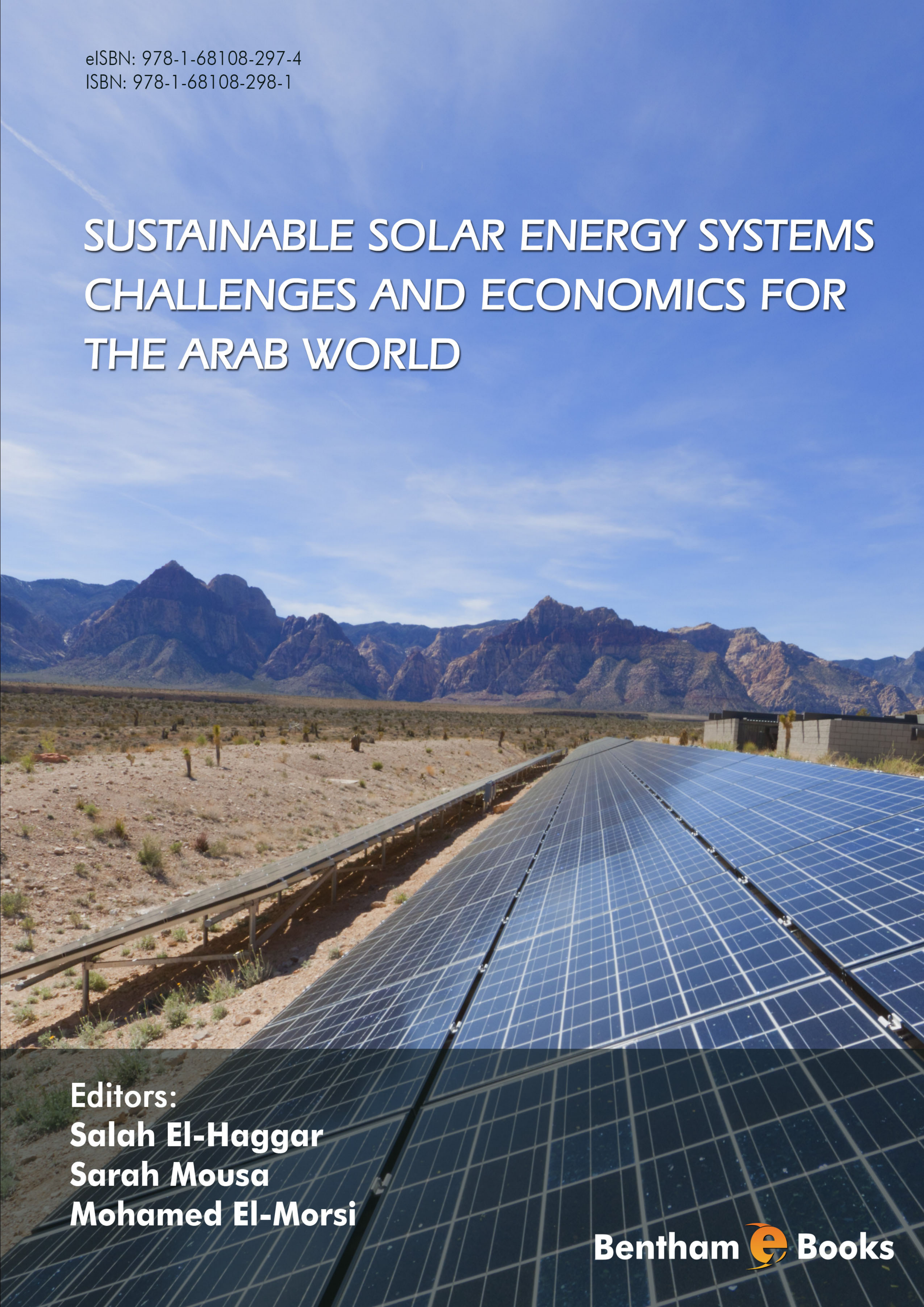

# SUSTAINABLE SOLAR ENERGY SYSTEMS CHALLENGES AND ECONOMICS FOR THE ARAB WORLD

Editors:
**Salah El-Haggar**
**Sarah Mousa**
**Mohamed El-Morsi**

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# SUSTAINABLE SOLAR ENERGY SYSTEMS

## *Challenges and Economics for the Arab World*

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# Sustainable Solar Energy Systems

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**PART 1: TECHNOLOGIES, BENEFITS AND CHALLENGES**

PART 2: ECONOMICS AND CASE STUDIES

# FOREWORD

Egypt and the Arab world are blessed with abundant solar energy resources. Located in the "sun belt" with powerful solar radiation and dependably clear skies, and having vast tracts of vacant desert land suitable for mounting solar installations, this region is the ideal venue for adoption of solar technology. A formidable challenge facing the Arab world, however, is to harness the seemingly limitless potential of solar energy as a practical engine for social and economic development. It is a challenge that Dr. Salah El-Haggar and the coauthors of Sustainable Solar Energy Systems meet head on.

This volume goes beyond conventional studies of solar technology and economics to address the everyday needs of underserved populations, particularly the rural poor. As Dr. El-Haggar and his co-authors vividly describe, even when fossil fuels (*e.g.* kerosene, diesel, wood) are available to such groups and are affordable, dependency on conventional fuels for household needs and agricultural work undermines their health, saps educational opportunity and blocks economic advancement. This is especially true for women and children.

The authors first provide the reader with a basic grounding in the science of solar energy, both thermal and photovoltaic, the engineering of solar energy systems and the economics of typical solar energy applications. As the authors point out, the world is in the midst of a veritable "solar revolution," with steadily falling prices for solar panels and continuous improvements in solar technologies.

Once past these basics, Dr. El-Haggar and his colleagues demonstrate how solar energy can readily be adapted for rural household and agricultural needs such as cooking, domestic hot water, heating, cooling and ventilation of houses, drying of agricultural products and off-th--grid electricity requirements. Of special importance for Egypt and the Arab world, which face chronic water scarcity, is the explanation of how solar energy can facilitate desalination, the conversion of seawater to fresh water.

The book ends with an ingenious study of how proven solar hot water heating technology can be adapted for large-scale poultry production. By using computer simulations, the authors show that not only is it technically feasible to substitute solar energy for much of the diesel fuel currently used to warm hen houses, but converting to solar makes compelling business sense for poultry farmers as well.

Dr. El-Haggar and his co-authors have deftly bridged the gap between the academic science of solar energy and the practical applications so desperately needed by underserved populations. This valuable handbook can lead to more rapid dissemination of solar technologies in the region and to better health, educational and economic opportunities for the rural populations of Egypt and the Arab world.

**Marc Rauch**
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# PREFACE

This book is unique in that, as far as the authors' knowledge, it is the only basic comprehensive guide to solar energy and the potential use of solar powered technologies for sustainable development, primarily on a grass-roots level. The book provides an introduction to basic concepts of solar energy, describes the mechanisms and benefits of related technologies, and suggests potential uses on a practical level by examining case studies. Detailed economic feasibility studies are presented in this book to encourage the implementation of sustainable technologies in the field of solar energy and help communities, especially in the Arab world, live a more sustainable life. The focus on the Arab world in this book stems from the noticeable changes in the environmental and political climates there which provide a great opportunity for the harnessing of renewable energy.

This book strikes a balance between simplicity and comprehensiveness in the fact that although no specialty background knowledge is needed to read it yet it offers broad understanding of solar energy and its applications.

The urgency of exploring alternative energy sources, especially in a region so detrimentally affected by current energy practices on environmental, humanitarian and political levels makes this book a crucial element in raising awareness and activism in the field.

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Our sincere appreciation goes to Dr. Khaled Nassar, Eng. Ghada Abdel Azim and Eng. Heidi El-Zanati for their contribution in Chapter 6, Chapter 8 and Chapter 9, respectively.

## CONFLICT OF INTEREST

The authors confirm that they have no conflict of interest to declare for this publication.

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# ABOUT THE AUTHORS

**Dr. Salah M. El-Haggar**, is a Professor of Energy and Sustainable Development and Chair of Mechanical Engineering Department, He received a B.Sc. and M.Sc. degree in Mechanical Power Engineering from Ain Shams University and Ph.D. from Washington State University, USA in 1983. He joined The American University in Cairo in 1987.

Dr. Haggar’s has more than 30 years' experience in Energy and Environmental Consulting and University teaching. Dr Haggar has been a visiting professor at Washington State University and at University of Idaho, U.S.A. Dr. El-Haggar received the outstanding teaching award from AUC in 1995 as well as a number of outstanding trustees awards. In 2009, Dr. El-Haggar received excellence in Research and creative endeavour award from AUC. In addition Dr. Haggar has 190 Scientific Publications in Environmental, Sustainable Development and Energy Fields, 51 invited presentation, 57 technical report, 16 books, one chapter in 6 different books.

Dr’s Haggar Environmental Consulting experience include 5 mega projects for Sustainable Building according to LEED certification (DAR premises, Mall of Egypt MOE, Credit Agricol CA, Union National Bank UNB, Zewail University), more than 40 Environmental/Industrial Auditing for major industrial identities, 20 Compliance Action Plan, 9 Environmental Impact Assessment in addition to his extensive consulting experience in Environmental Engineering, Environmental Auditing, Coastal Zone Management, Environmental impact assessment EIA, Environmental management systems EMS, Energy management, Hazardous and non-Hazardous Waste management, Recycling, Pollution prevention and waste minimization, zero pollution, Biogas/Solar/Wind technology, Community/Desert development, Solid and industrial waste, environmental assessment for the local government and private industries.

Dr. El-Haggar developed a new concept to assess the life cycle of a product according to cradle-to- cradle concept instead of cradle-to-grave concept used worldwide until today. This concept was developed based on 25 years of intensive and continual effort at AUC in the area of waste management with all types of wastes to prove the practicality of this concept from engineering point of view. Recently, a formula and indicator for sustainable development was developed for the first time worldwide according to cradle-to-cradle concept. The formula was included in his recent book published by Elsevier Academic Press entitled “Sustainable Industrial Design and Waste Management: Cradle-to-Cradle for Sustainable Development”. This book is the first book worldwide to demonstrate the concept of cradle-to-cradle to protect not only the environment but also the natural resources in terms of business plans.

**Sarah Mousa i**s a 2011 Fulbright Scholar to Egypt, where she studied the potential of solar technologies for use in underprivileged communities. She is the founder of Shamsina, a social enterprise based in Al-Darb Al-Ahmar that produces low-cost solar powered water heaters from local materials.

Sarah obtained Master of Arts in Arab Studies and Development from Georgetown University in 2014; 2011 Fulbright Scholar; 2010 Bachelor of Arts from the Woodrow Wilson School of International and Public Affairs at Princeton University.

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# INTRODUCTION

The current use of fossil fuels as the main energy source is unsustainable and is associated with both humanitarian and environmental insecurity. According to the International Energy Agency (IEA) the world global energy demand increased from 1990 to 2000 by 14.69% and from 2000 to 2010 by 27.17%. This current rate of usage is alarming as this growing energy demand can outstrip fossil fuel energy supply. This surge in energy demand results in an increase in greenhouse gas emissions that contribute to environmental degradation despite all international efforts to curb the rise of greenhouse gas emissions. Proposals to lower emissions are often met with controversy due to the argument that reducing fossil fuel usage will be associated with decreased development rates. Renewable energy, however, presents a viable alternative to traditional energy sources, especially on a small-scale level. As the world continues to consume fossil fuels and harm its own land and populations the resultant climate change and associated rise in sea level will first and foremost affect vulnerable countries like those on the Mediterranean. The expanding world population, with its increasing development, especially in the Middle East and North Africa (MENA) is using fossil fuels at an untenable rate. Despite the vast potential for renewable energy which the MENA region possesses, exploitation, conflict and instability associated with energy resources remain a major political and economic obstacle to development. The MENA region lies on the global sun-belt and is potentially one of the most productive regions for solar energy usage. The possibility for solar technologies to improve living conditions by providing a clean, sustainable energy source and expand local employment opportunities is especially significant among remote and low-income communities in this region. There is potential for great enthusiasm for alternative energy sources throughout the MENA region, as displayed by select underprivileged communities which have experimented and embraced solar technologies.

The objective of this book is to provide an overview of solar energy, present several solar technologies and suggest applications that can greatly benefit low-income, developing communities in the geophysical, societal and cultural context of MENA.

The book begins by providing a brief introduction about solar radiation and climate change in chapters one and two, respectively. Chapter three then presents the negative impacts of fossil fuels and how can solar energy offer a viable alternative. Subsequently chapter three provides a brief overview of selected solar powered technologies, including their mechanisms and possible applications. The implementation of these technologies is presented in Chapter five. Chapter six then focuses on natural lighting and studies its importance, and significant influence on electric bills.

The energy solutions in MENA which is a leading candidate for solar energy use are discussed in Chapter seven. Finally, the last two chapters in the book present economic feasibility studies that are necessary to encourage the implementation of sustainable technologies in the field of solar energy in order to achieve more sustainable communities in the MENA region.

# PART I: TECHNOLOGIES, BENEFITS AND CHALLENGES

## CHAPTER 1

# Sunlight and Solar Radiation

**Sarah Mousa**[2,#], **Mohamed El-Morsi**[1] and **Salah El-Haggar**[1,*]

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**Abstract:** The sun is a hot sphere of gas with an internal temperature of 15 million degrees Celsius, the surface of the sun is at a temperature that is approximately 5500 Kelvin. The total power emitted by the sun is $3.83\times10^{26}$ W, and the intensity is about 6.33×107 W/$m^2$. The solar radiation reaching the earth's surface, 1367 W/$m^2$, is reduced by absorption, reflection and scattering of the atmosphere. Solar radiation and its intensity on earth's surface varies based on latitude and longitude location, time of year, time of day, local atmospheric variations such as vapor, cloud or pollution concentration, and atmospheric effects such as absorption and scattering. All these are crucial factors when considering the optimum design and location for solar powered technologies. This chapter will help us consider where, when and how solar radiation should be harnessed in order to take the greatest advantage of energy reaching the earth's surface.

**Keywords:** Air Mass, Atmospheric gases, Electromagnetic spectrum, Extraterrestrial, Gamma rays, Infrared, Intensity of solar radiation, Mie scattering, Photon, Photosphere, Power emitted by the sun, Radio waves, Rayleigh scattering, Solar insolation, Sun internal temperature, Sun surface temperature, Ultraviolet, Visible light, X-rays.

## INTRODUCTION

This chapter provides sunlight and solar radiation background information needed

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**Salah El-Haggar, Sarah Mousa & Mohamed El-Morsi (Eds.)**

for understanding the basic mechanisms of solar powered technologies and how they can be used for sustainable development. This includes the features of the sun, the light and energy which it provides, and the factors which impact the intensity of this energy on earth's surface.

## SUNLIGHT

The sun is a hot sphere of gas with an internal temperature of 15 million degrees Celsius [1]. Nuclear fusion reactions at the core which convert hydrogen into helium contribute to the high internal temperatures. The surface of the sun is called the photosphere and its temperature is approximately 5500 Kelvin [2]. Sunlight is a form of electromagnetic radiation (an energy form that travels in waves through space) and can be described in terms of an electromagnetic spectrum with light consisting of certain wavelengths. The power emitted from the sun is composed of a wide range of wavelengths in the electromagnetic spectrum, and appears white or yellow to the human eye [3].

Visible light is only one subset of a spectrum which constitutes light emitted by the sun. Fig. (**1.1**) illustrates the electromagnetic spectrum and indicates wavelengths which correlate with each segment of the spectrum. It is notable, as indicated in Fig. (**1.1**), that shorter wavelengths are correlated with lower energy.

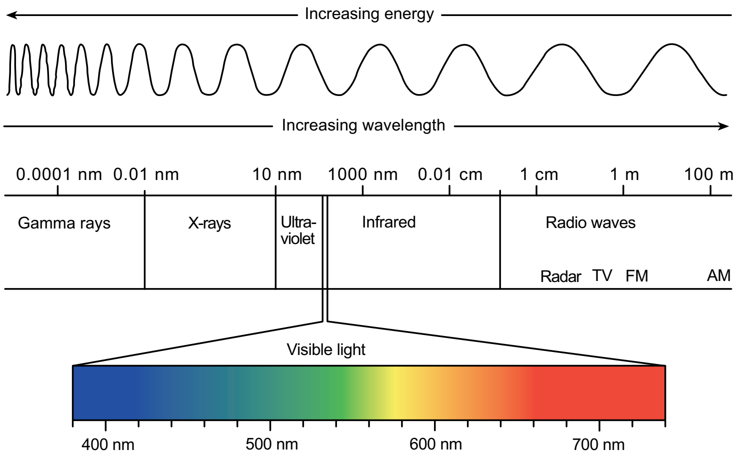

**Fig. (1.1).** The electromagnetic spectrum [4].

In addition to wavelengths, sunlight can also be described in the form of packets of energy called photons. A photon is characterized either by its wavelength ($\lambda$) or energy ($E$). Wavelength and energy have an inverse relationship, as shown by Eq. (**1-1**) [3].

$$E = \frac{hC}{\lambda} \tag{1-1}$$

In Eq. (1-1), ($h$) represents Plank's constant and ($C$) is the speed of light. According to this formula, the longer the wavelength of a photon, the lower the corresponding energy is, and the shorter a wavelength is, the higher the corresponding energy. The unit of energy commonly used to describe photons is the electron-volt (eV), which is the amount of energy needed to raise an electron 1 volt.

The photon flux is relevant when considering the intensity of energy emitted from the sun. The photon flux is the number of photons per unit area per second; the concept will be important in photovoltaics when considering the electrons generated and thus current produced, by a solar cell. The photon flux, however, does not provide details on photon wavelength or energy, either one of which would additionally be needed to calculate the power density for photons at a particular wavelength. Multiplying the photon flux by the energy of the photons yields the power density. One noteworthy implication is that higher energy photons will require a lower photon flux than lower energy photons to yield a similar power density. Spectral Irradiance ($F$) is the power density of a photon at a particular wavelength and is another important concept in photovoltaics [3].

The total power emitted by the sun, $3.83\times10^{26}$ W [1], is calculated by multiplying emitted power density by the surface area of the sun, 6 million km$^2$ [2], and the intensity of the solar radiation, $H_{sun}$, is about $6.33\times10^{7}$ W/m$^2$, as shown in Fig. (**1.2**). The solar radiation at the top of the earth's atmosphere, extraterrestrial radiation, can be calculated by using the total power emitted by the sun's surface and accounting for the earth's distance from the sun. A yearly average value for the extraterrestrial radiation, $H_O$, is the solar constant 1367 W/m$^2$ as shown in

## CHAPTER 2

# Climate Change

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**Abstract:** The earth's temperature is determined by the incoming radiation from the sun and the outgoing infrared radiation emitted by the earth. Radiation emitted by the earth is largely dependent on the composition of the earth's atmosphere. The accumulation of greenhouse gases, due to human activities, in the earth's atmosphere absorbs infrared radiation emitted by the earth's surface and keeps it in the atmosphere. With today's rate of fossil fuel utility, compounds are released into the atmosphere, soil and seas on a daily basis, resulting in significant changes in the atmosphere. In recognition of how damage caused by fossil fuels harms an environment shared by all, the United Nations Framework Convention on Climate Change (UNFCC) put forth the Kyoto Protocol in 1997. Climate change is among the many reasons, which make increased research on and immediate implementation of solar powered technologies not simply a luxury, but a necessity for the future environmental wellbeing of earth. This chapter presents the problem of global warming, its reasons and efforts led by decision makers to seek various approaches to tackle the core of the problem and mitigate its severe environmental, economic and social impacts.

**Keywords:** Anthropogenic gases, Cap-and-trade, Carbon credit, Carbon dioxide, Certified emission reductions, Clean development mechanism, European Union allowances, Global warming, Greenhouse gases, Kyoto Protocol, Terrestrial temperature.

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**Salah El-Haggar, Sarah Mousa & Mohamed El-Morsi (Eds.)**

## INTRODUCTION

It is important to understand the state of the existing climate and the effect of the current energy usage on it before discussing solar powered technologies and the benefits associated with their use. Fossil fuels, including coal, petroleum and natural gas, are currently the most prevalent source of energy worldwide. These sources contribute to global warming as will be discussed in this chapter. This chapter will also address the international responses to this phenomenon.

## GLOBAL WARMING

The temperature on the earth's surface is closely associated with weather patterns which make it inhabitable for living beings. This temperature is determined by two aspects: first, the incoming radiation from the sun and second, the outgoing infrared radiation (heat) emitted by the earth. Radiation emitted by the earth is largely dependent on the composition of the earth's atmosphere. If there were no atmosphere, earth's temperature would be -18°C whereas the earth's average temperature is 15°C [1].

The presence of $CO_2$ in the earth's atmosphere plays a crucial role in decreasing radiation emitted from earth. Fossil fuels contain a high amount of carbon. Human activities involving fossil fuel energy result in the release of anthropogenic gases (including $CO_2$, methane, ozone, nitrous oxides and chlorofluorocarbons) which impact the earth's atmosphere. The resulting increasing amount of gases in the atmosphere absorbs infrared radiation emitted by the earth's surface and keeps it in the atmosphere instead of permitting it to be radiated to deep space. The release of these pollutants, or greenhouse gases, through the use of fossil fuels is a routine occurrence, and can be either expected or accidental. With today's rate of fossil fuel utility, compounds are released into the atmosphere, soil and seas on a daily basis, resulting in significant changes in the atmosphere [2]. The greenhouse gas (GHG) emissions has been increasing almost exponentially. According to the World Bank indicators the GHG emissions has increased from 23 Gt in 1990 to 35 Gt in 2011, which is about 53% increase.

Other human activities which contribute to the increase of $CO_2$ levels in the atmosphere include the destruction of forests, since this reduces subsequent rates of photosynthetic $CO_2$ assimilation until ground cover is restored. The change in atmosphere caused by these factors potentially increases terrestrial temperatures, threatening the environmental status quo. Fig. (**2.1**) indicates the upward shift in $CO_2$ concentrations over the past century, and particularly in recent decades, and the associated rise in terrestrial temperatures [1].

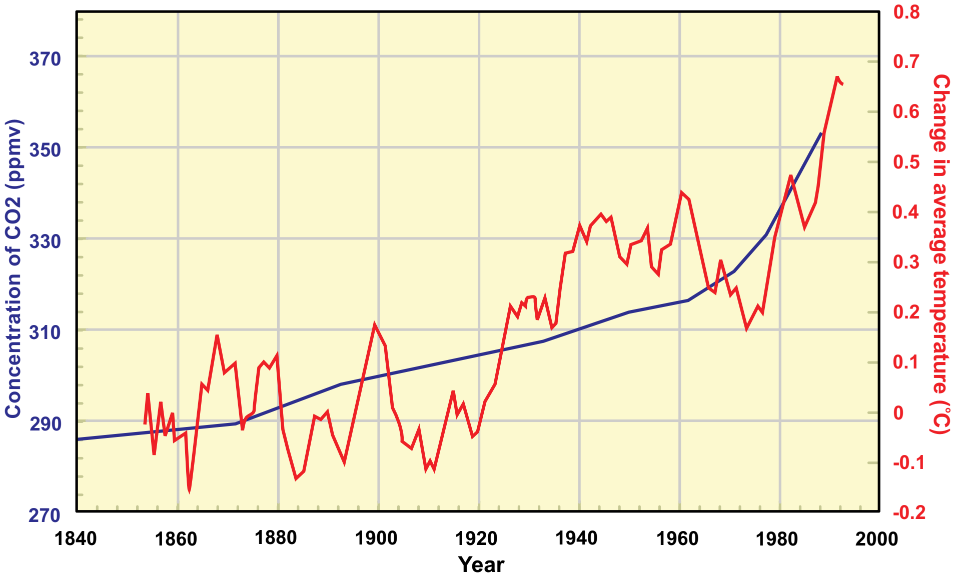

**Fig. (2.1).** Concentration of $CO_2$ and average terrestrial temperature [1].

Some studies suggest that by 2030, $CO_2$ levels could double—leading to an upward shift in temperature ranging from 1-4°C. This in turn could affect wind patterns and rainfall, causing a rise in sea levels and the interior of continents to dry [1]. The International Energy Agency (IEA) announced that carbon-emissions reached a record high in 2011 [3]. Along with a continued rise in temperature, rise in sea water levels, intensified storms, crop failures and increased droughts are among the expected repercussions of climate change and are already evident [4].

Opponents of the notion of global warming suggest that if $CO_2$ levels and the temperature of the earth are considered over thousands of years, a natural cycle of rising and falling temperatures exists. While there is indeed a clear pattern of rising and falling temperatures, the fact remains that in recent decades $CO_2$ levels

## CHAPTER 3

# Solar Energy and Associated Benefits

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**Abstract:** The environmental problems associated with the use of fossil fuels can be largely diminished by changing to renewable energy sources. Traditional energy sources are harmful to the environment on both local and global scales, largely because their use is associated with the emission of greenhouse gases. Solar power systems, along with those which rely on other renewable energy sources such as wind and hydroelectric power, produce minimal carbon emissions. Considering its abundance, solar energy presents itself as a clean viable main energy source alternative to traditional reliance on fossil fuels. On the economic level, solar energy has the potential to serve as a stimulant for economic growth and sustainable development. Throughout the world, and particularly in developing countries, access to energy is highly correlated with social and economic factors. Access to affordable energy for all is crucial for economic growth. Also, the social benefits associated with the usage of solar energy are potentially most significant for underserved populations in developing countries. This chapter shows how solar energy presents itself as an alternative to traditional energy sources that is healthier for both the environment and humanity, and has the potential to enhance the social and economic fabric of a community.

**Keywords:** Air pollution, Global mean temperature, Health, Human development index, Respiratory diseases, Solid fuel.

## INTRODUCTION

This chapter continues the discussion started in the previous chapter, Chapter 2,

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about the negative impacts of fossil fuels and presents the benefits associated with using solar energy and related technologies. It is interesting to know that the amount of solar energy that reaches earth every hour is greater than the energy that the world's population consumes in a year [1]. The benefits associated with the exploitation of this energy, both to the environment and humanity, are innumerable. More details and examples about this clean source of energy are discussed in this chapter.

## SOLAR POWER

Solar power is the conversion of sunlight into electricity. This can be accomplished by several different means, one of which is Concentrated Solar Power (CSP), a direct solar thermal process. Several solar powered technologies rely on CSP, including solar cookers, dryers, and water heaters. Solar power can also be directly converted into electricity, as is the case with photovoltaic panels. Solar cells which comprise these panels directly convert sunlight into electricity. Considering its abundance, solar energy presents itself as a viable alternative to traditional reliance on fossil fuels as a main energy source [2].

Fossil fuels, including coal, petroleum and natural gas, are problematic on several fronts. Fossil fuels are associated with a number of hazards relating to the environment, human health, security and economic stability. These hazards place increased pressure on a need for investment in renewable energy sources. The remainder of this chapter will discuss the benefits of solar power, especially as opposed to traditional energy sources. It will present a case for increased use of solar power technologies, not as an end goal in and of itself, but as a means for protecting the environment and public health and as a catalyst for social and economic development.

## ENERGY AND ENVIRONMENT

The environmental problems associated with climate change, discussed in Chapter 2, can be largely diminished by transitioning from fossil fuels to renewable energy sources. Traditional energy sources are harmful to the environment on both local and global scales, largely because their use is associated with the emission of greenhouse gases. Environmental degradation is felt even more strongly in developing countries, which struggle to respond to climate change and rely on environmentally sensitive activities that are especially harmed by fossil fuel use, such as agriculture and fishing.

Solar power systems, along with those which rely on other renewable energy sources such as wind and hydroelectric power, produce minimal carbon emissions. Solar power is thus a clean energy source, associated with no harm to the environment. Wiser use of this natural resource can result in a lower dependence on fossil fuels, thus reducing emissions and improving both the local and global environment.

Fig. (**3.1**), shows predicted climate change over a century for given various scenarios. In a world that seems headed for rapid development (A1), this graph makes clear the pressing need for increased use of alternative energy technologies (scenario B1). Special consideration for the amount of harm that a change in temperature, by even a single degree, could result in making the graph below a stark warning for continued fossil fuel-reliant global development.

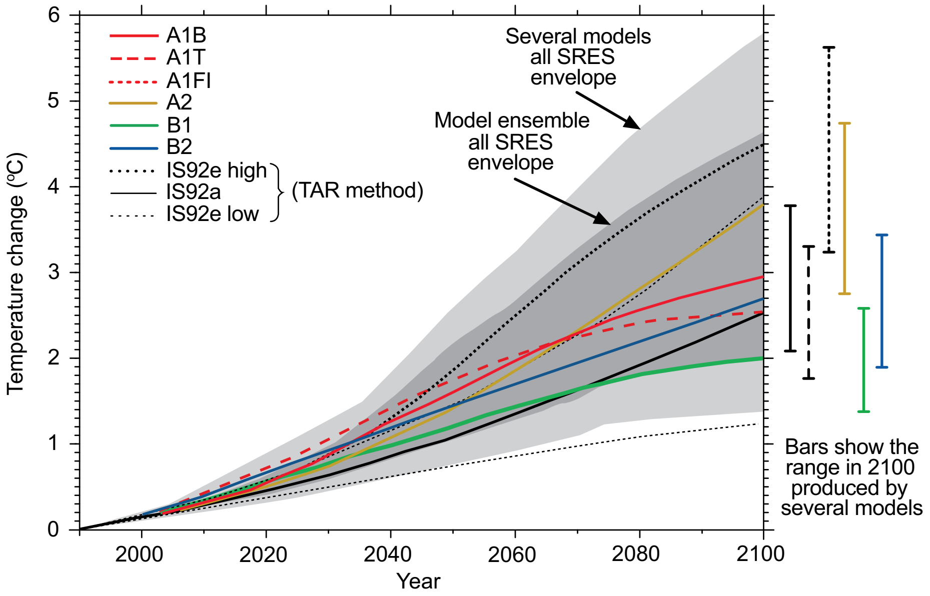

**Fig. (3.1).** Global mean temperature change and future changes for six illustrative special report on emissions scenarios (SRES) [3].

## CHAPTER 4

# Solar Powered Technologies

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**Abstract:** Solar energy is a viable alternative to traditional energy sources it is healthier for both the environment and humanity, and has the potential to enhance the social and economic fabric of a community. In this chapter the basic mechanisms of several solar powered technologies are addressed. These technologies include passive building design, solar dryers, solar cookers, solar water desalination, solar water heating, solar electricity, and solar fuels.

**Keywords:** Biofuels, Evacuated tube, Flat plate, Humidification-dehumidification, Hydrogen, Overhangs, Passive solar building, Photosynthesis, Photovoltaic, Reverse osmosis, Solar cooker, Solar desalination, Solar dryers, Solar fuels, Solar still, Tent dryer, Thermal chimney, Thermal mass, Trombe Wall, Trough.

## INTRODUCTION

This chapter provides a brief overview of selected solar powered technologies, including their mechanisms and possible applications. As a continuation for the previous chapter, this chapter provides a brief overview of selected solar powered technologies, including their mechanisms possible applications and their potential benefits. This prepares the reader and furnishes the floor for the following chapter where the implementation of these different technologies is being presented.

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Chapter 5 will feature specific case studies involving the technologies discussed here.

## PASSIVE SOLAR BUILDING DESIGN

The objective of passive solar building design is to allow sunshine into a building when heat and light are needed and to prevent heat from entering during warmer periods. If such designs can be integrated into the structure of a building, the need for energy sources to maintain moderate temperatures can be significantly reduced. Using passive solar design techniques make buildings more energy-efficient and allow for less reliance on traditional energy sources for lighting, heating and cooling. Passive solar is optimal when designed into a building's original structure; making alterations to a structure can be much more difficult [1].

There are a number of features which can be integrated into a building design to make it more energy efficient. The first requisite for a passive solar building is proper orientation. The longest side of the building should face south so that maximum surface area is exposed to the sun, thus allowing for the greatest amount of light to enter during the day. Second, windows and skylights as well as outdoor trees should be strategically placed. The appropriate placement of trees can result in significant reductions in heating or cooling costs. With the appropriate placing of skylights and windows, a good solar building should not require active lights before sunset. Furthermore, window sizes and glazing (double glazing, for example, helps retain heat) should be taken into consideration. The third consideration should be shading and overhangs to reduce solar gain during summer months but permit it during winter months. Fourth, thermal mass should be used in construction to allow for the maximum storage of heat during winter months. Building materials such as concrete, tile, bricks and stones have a lot of thermal mass and if incorporated into a structure can reduce the need for heating during winter [2].

To minimize the need for cooling, for hot regions like the Middle East and the Arab world, high albedo building surfaces can be used to reduce solar gains, buildings can be oriented to catch the prevailing wind direction for wind-driven natural ventilation. Also, urban designs that minimizes the heat island effect can be adopted. This can be achieved through considerable shading *via* overhangs, awnings and vegetation, and anchoring buildings thermally to cooler ground using deep foundations and tile/stone flooring. Additionally, ground source heat exchange can be used to provide additional low energy cost cooling

The solar path and its seasonal variation, as discussed in Chapter 1, must be taken into consideration when determining window orientations in a solar building. Fig. (**4.1**) features a passive solar building. As shown in the figure, the orientation of windows and panels accounts for the seasonal variation in the suns zenith so that sunlight can enter during the winter, but can be shielded during the summer [3].

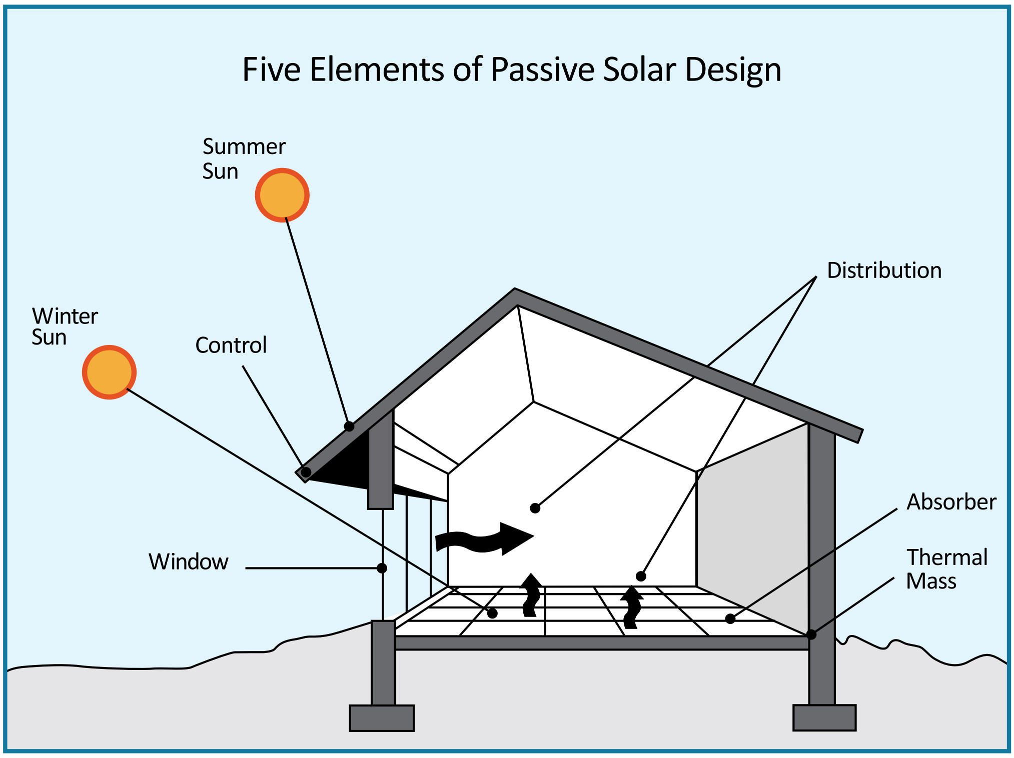

**Fig. (4.1).** Five elements of passive solar design [3].

A passive solar building can also include a ventilation mechanism referred to as a solar or thermal chimney. In its simplest form, it is a chimney that is painted black to attract solar energy. During the day, the hot air fills the chimney to create a

## CHAPTER 5

# Solar Power and Sustainable Development

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**Abstract:** The need to account for sustainable development when it comes to energy is crucial; the major energy sources in current use are unsustainable in that they harm the environment and deplete resources for current generations and especially for future ones. Significant amounts of energy can be saved if a technology used to accomplish a given task is designed efficiently. Examples include the use of (i) passive building design to meet the heating and cooling demands of buildings, and (ii) solar energy for water heating, generating electricity, water desalination and cooking. Several case studies, presented in this chapter, from different geographic locations show that several technologies can be adopted to meet a certain energy use without scarifying the environmental, social, cultural, and/or aesthetic standards.

**Keywords:** Arab world, BedZED, Brundtland report, Case studies, Falkenmark index, Gaza, Hybrid ventilation, Masdar, MENA, Middle East, Passive, Solar chimney, Solar dryers, Solar energy, Sustainable development, Technologies, Thermal mass, Water desalination, Water scarcity, Zero energy.

## INTRODUCTION

This chapter examines ways in which the solar powered technologies, discussed in Chapter 4, can be used for sustainable development in different regions of the world with a special focus on Egypt and the Middle East. The chapter focuses on successful case studies and also reveals the potential for solar energy technologies

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in the Middle East. Case studies discussed in the Middle East are applicable worldwide, but the reader should take into consideration the availability of solar energy in the Middle East, as well as the social and cultural aspects which must be taken into account for the successful implementation of solar power technologies.

The chapter individually considers how each of the technologies discussed in Chapter 4 can be locally produced and developed as a step towards building awareness and increasing local usage of renewable energy technologies as well as building self-reliance from a grass-roots level. The clean and affordable energy obtained through the use of these solar powered technologies can potentially transform livelihoods, not only among those without any source of reliable energy, but also among the entirety of a population since all can integrate at least some of these technologies into their lifestyle and will benefit from a clean environment.

## SUSTAINABLE DEVELOPMENT

In its 1987 Brundtland Report, the sustainable development was defined by the UN as "*development which meets the needs of the present without compromising the ability of future generations to meet their own needs*" [1]. Over the ensuing years and decades, a more comprehensive definition of sustainable development has surfaced. In its 2005 World Summit Outcome Document, three major pillars were highlighted by the UN for sustainable development: Social development, economic development and environmental protection. Arguments subsequently arose that culture should be an integrated part in the sustainable development, leading to the recognition of a fourth pillar. Cultural diversity was deemed an integral component of societies, associated with intellectual, emotional, moral and spiritual existence, which should be protected [1].

The need to account for sustainable development when it comes to energy is crucial; the major energy sources in current use are unsustainable in that they harm the environment and deplete resources for current generations and especially for future ones. Current energy sources are finite, meaning that their current rate of use will leave future generations without the resources to meet their energy needs. Not only the primarily technical aspects of solar powered technologies had an effect on the success of the products, but also factors that have included culture, aesthetics and appropriate technology played a significant role in that success. The word “appropriate technology” is often used to refer to the technology that is tailored to achieve a certain task efficiently, at the same time meeting specific use of energy and certain cultural, environmental and/or aesthetic standards.

There are arguments that renewable energy technologies, including solar powered technologies, are not always sustainable. The construction process of solar powered technologies sometimes consumes significant amounts of energy. This is especially the case with photovoltaic panels, which are comprised of silicon cells. Some of these materials are not only expensive, but are also rare and are in potential risk of depletion [2]. While some of these arguments against the sustainability of solar powered technologies may hold some validity, it is important first to consider the long term benefits of solar powered technologies and second to note that renewable energy research is relatively nascent and that more efficient technologies are being discovered by the day.

## PASSIVE BUILDING DESIGN

Passive building design is a well-known proven concept that can help in reducing the heating and cooling demands of buildings [3]. However, in metropolitan areas, noise, pollution and urban heat island effects challenges the design. Several successful case studies of passive building design have been reported from different parts of the world, examples include the science and technology museum building on the eastern edge of Hangzhou, China [4], the library and Division of Art, Design and Architecture at the Judson College in Elgin, Illinois, US, [5], the Frederick Lanchester Library at Coventry University, UK, [6], the School of Slavonic and East European Studies at University College London, UK, [7] and the Queens Building at DeMontfort University, Leicester, UK [8]. In the subsequent sections the buildings from China and the US are presented as examples for passive building designs.

The science and technology museum in China [4] is an office building with four storeys in addition to a basement that uses hybrid ventilation for space

## CHAPTER 6

# Natural Lighting in Buildings

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**Abstract:** Natural lighting is an essential element in successful design in order to decrease the electrical lighting energy consumption while ensuring visual comfort such as the reduction of glare. This chapter presents the topic of daylighting as it pertains to the urban scale. The chapter first provides an overview of the several benefits of daylighting in various applications. Some fundamentals about daylighting are then presented. This is followed by the presentation of the concept of solar envelopes as an important aspect of daylighting in the urban scale. Then different studies pertaining to daylighting at the urban scale are presented.

**Keywords:** Climatic daylighting metrics, Daylighting, Dynamic daylighting metrics, Energy, Fresnel lenses, Light redirection, Light wells, Lighting, Radiance, Simulation, Sky types, Solar tubes, Urban design, Urban sprawl, Window treatment.

## INTRODUCTION

Daylighting is the process of trying to provide natural sun light to internal and external spaces during the day through the design of openings, surfaces, fenestrations, facades, building elements and other active elements. The main goal is to increase the amount of natural light while decreasing electrical lighting and ensuring visual comfort such as the reduction of glare. This chapter presents the topic of daylighting as it pertains to the urban scale. The chapter first provides an overview of the several benefits of daylighting in various applications. Some

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fundamentals about daylighting are then presented. This is followed by the presentation of the concept of solar envelopes as an important aspect of daylighting in the urban scale. Then different studies pertaining to daylighting at the urban scale are presented.

## BENEFITS OF NATURAL LIGHTING

Providing adequate natural light in building spaces and also outdoors is a very important aspect for several reasons. Firstly, providing natural sunlight can reduce the amount of electrical lighting required to provide the desired level of illumination in and around buildings. This in turn can reduce the amount of energy required for electrical lighting and thus reduce the amounts of harmful emissions resulting from electricity generation. Consider for example that the United States consumes about 412 billion kilowatt-hours (kWh) of electricity for commercial and residential lighting. This means that 15% of the residential and commercial electricity consumption was attributed to lighting [1].

In particular, institutional and commercial buildings, as well as street lighting used more lighting energy in 2014 than the residential sector totaling about 262 billion kWh (19% of the total electric energy consumed). Residential lighting consumption on the other hand was about 150 billion kWh (14% of total electric energy consumed). The impact of reducing the amount of electrical energy assigned to electrical lighting by enhancing the use of natural lighting becomes clear.

Secondly the health benefits of daylighting have long been known. In principle, light in general and daylight in particular orchestrates the circadian response and influences the metabolism and the endocrine and hormone systems as well as the production of melatonin, dopamine, and serotonin [2]. Daylight additionally is partly responsible for Vitamin D in our bodies by way of photosynthesis through our skins. This is a very important factor in bone diseases and Multiple sclerosis. It is also well known that light has an impact of what is known as Seasonal Affective Disorder (SAD) as well as depression, stress and anxiety.

In addition to the above benefits, light also affects the quality of life and aesthetics of the building and urban spaces. Therefore daylighting legislation in different countries have been implemented to assure adequate daylight. Most countries have in their building ordinances requirements for solar zoning legislation, which basically sets certain limits on setbacks, street widths, and building heights to ensure that building spaces have adequate access to sky and/or the sun. In the English law for example there are provisions for what is known as “right to light” which is a form of easement which guarantees that buildings with windows maintain the same level of access to daylight with any addition of modifications to adjacent buildings. In addition most building codes will set requirements for the presence of windows as well specifying their sizes. Additionally, sustainability certification schemes such as the US green building rating system LEED, will award buildings which achieve certain levels of daylight.

For specific building types, daylight has special importance. For example, it has been shown [3, 4] in schools that children score better on tests in naturally lit classroom. In addition to the fact that natural light has been proven to improve standardized test scores, eliminate common distractions and improve health and growth, it also has been shown to reduce late-day energy loss. In the workplace it has shown to increase productivity in has also been proven to increase sales [5]. Daylight has also been shown to help in the healing process in hospitals [6].

## DAYLIGHTING FUNDAMENTALS

This section presents important concepts pertaining to daylighting design. The starting point to any daylighting design is understanding the source of the natural light. Natural light comes either from the sky dome or the direct sun beam. In order to simulate and design with daylight, a number of models of the sky and sun have been developed. The most basic sky model is what is known as the Uniform Luminance Model which describes a sky of constant brightness. The main purpose of this model is to represent a heavily overcast sky, where no sun can be seen. However, it has long been known that the brightness of an overcast sky changes gradually from being darker at the horizon and brighter at the zenith.

Therefore, the standard model for modeling overcast sky is the CIE (Commission internationale de l'éclairage or the International Commission on Illumination) Standard Overcast Sky, which was originally known as the Moon and Spencer

## CHAPTER 7

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# Challenges in The Arab World

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**Abstract:** The MENA region receives between 22% and 26% of all solar energy striking the earth. This translates to a potential for solar energy per square kilometer per year equivalent to the energy generated from 1 to 2 million barrels of oil. Despite this, the region continues to deplete limited resources and escalate tensions over competition for the use of these resources. The MENA region only holds 1.8% of the world installed capacity of solar water heaters and 0.68% of the installed PV worldwide capacity. Governments of the Arab world often don't regard environmental protection and associated methods, renewable energy, as an economically or developmentally important. As a result the effort is often unfocused and driven simply by modest concern for international treaties. This chapter presents some of the challenges facing the implementation of solar powered technologies in the Arab world. These challenges are related to both the technologies themselves and the political and social factors.

**Keywords:** Arab world, Battery, Efficiency, Obstacles, Passive solar buildings, Photovoltaic, Solar cookers, Solar dryers, Solar electricity, Storage, Water heaters.

## INTRODUCTION

The Arab world possesses great potential for renewable energy; the vast amount of available solar energy and land that can be exploited makes the region an ideal location for the implementation of solar energy technologies. Despite this, the

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region continues to deplete limited resources and escalate tensions over competition for the use of these resources. As the region continues to consume fossil fuels, it is foremost harming its own land and populations as the resultant climate change and associated rise in sea level will first and foremost affect countries on the Mediterranean.

The implementation of solar energy technologies discussed in this book is a viable alternative to current energy sources. Solar energy presents itself as an inexhaustible resource which does not harm the environment. Once technologies are in place, a sustainable source is provided. Nonetheless, there are several challenges on geographical, technological, economical, institutional, and socio-cultural levels which are obstacles to solar energy usage and must be addressed.

## AVAILABILITY OF SOLAR ENERGY

Solar energy is not necessarily a suitable energy source worldwide. As discussed in Chapter 1 and illustrated in Fig. (**1.1**), solar energy availability varies greatly depending on geographic location. The availability of solar energy also varies in a particular location depending on the season of the year and time of day. Atmospheric effects also discussed in Chapter 1, such as cloud coverage, could also limit the availability of solar energy. These factors mean that not all locations are ideal for the harnessing of solar energy. The Saharan Desert, both for its proximity to the equator and clear desert skies, is one of the most optimal locations for solar energy. Other areas with close proximity to the equator are also appropriate for the implementation of solar energy technologies. Before considering whether or not solar power technologies are appropriate for a particular community, the local availability of solar energy must be taken into account. The Middle East is one of the most optimal locations for the harnessing of solar energy worldwide. The region's solar energy endowments position it to lead the world in the field of renewable energy.

## ENERGY EFFICIENCY

The amount of available solar energy does not alone convey the usefulness of a solar powered technology in a particular location. Current technologies are not able to take full advantage of all available solar energy. The amount of solar energy that can be harnessed for usable heat or electricity by these technologies is often very limited and must be taken into account when deciding whether or not the device will be useful.

In terms of photovoltaic panels, for example, energy harnessed cannot be directly used. Solar panels generate direct current (DC), while most equipment requires alternating current (AC). An inverter is needed, and is typically around 90% efficient. From the amount of available energy the overall efficiency of photovoltaic panels is at highest 25% [1]. For other solar powered technologies, efficiency must be considered along with price. In terms of water heaters, for example, flat panel heaters are less expensive but are also less efficient than evacuated tube heaters. Passive heaters are less expensive and rely solely on solar energy, but are also less efficient than water heaters which incorporate pumps. Energy efficiency is one of the main factors which must be considered when selecting a solar powered technology for implementation.

## STORAGE EFFICIENCY

Energy is not evenly available throughout a day, and is not always needed for immediate usage. Technologies typically generate the greatest amount of power at midday, when the sun is most directly available, but not necessarily when needed. Since solar energy garnered is variable at any given time, it can rarely be relied on to power equipment directly. Energy garnered by photovoltaic panels requires a battery that stores the energy and provides it at a constant rate to equipment when needed. Batteries often do not store all energy garnered by a system, and thus add to its inefficiency. Storage efficiency must be accounted for when considering the overall efficiency of a system [1]. Furthermore, the cost of a battery and the cost of its replacement when needed must be accounting for when considering the total cost of a system. Storage batteries become less efficient with usage, and have limited lifetimes [1].

## COST EFFICIENCY

The cost of implementing solar powered technologies, *versus* more common fossil fuel powered technologies, must be considered. Often times, however, those who consider solar power overlook running costs of equipment. Both initial costs and

# PART II: ECONOMICS AND CASE STUDIES

# CHAPTER 8

# Feasibility of Solar Energy

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**Abstract:** A model is developed to study the economic feasibility of adopting two kinds of solar technologies namely; solar water heaters and photovoltaics to substitute traditional systems in the residential sector. The model is a decision support system tool that guides investors and decision makers on the optimal scheme to utilize their funds and maximize the return on investment using an optimization approach over a duration of 10 years. The model considers offering a subsidy to support the diffusion of the systems through an initial fund of $1,500,000 in terms of a line of credit. The model computes the net present worth of the project and the line of credit payback period. In addition, the model provides annual percentages of the amount of money to be used in the reinvestment versus the amount used to pay back the line of credit. A case study is conducted and three proposed scenarios are applied namely; lease, loan and power-cuts tariff. The results of the study shows that the SWH line of credit payback period for the Lease, Loan and Power-Cut Tariff are 10, 9, and 10 years while the PV line of credit payback period for the Lease, Loan and Power-Cut Tariff are 8, 5, and 5 years.

**Keywords:** Decision support system tool, Economic challenges, Energy bond, Feed-in tariffs, Grants, implementation strategies, Lease, Line of credit, Loan, Net present worth, Optimization, Payback period, Photovoltaic panels, Power cut tariff, Rebates, Solar energy, Solar water heaters, Subsidy, Sustainable systems adoption, Tax reduction.

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## INTRODUCTION

The main purpose of this chapter is to discuss the economic feasibility and encourage the implementation of sustainable technologies in the field of solar energy in order to achieve more sustainable residential communities hence reducing carbon emissions as well as meeting the required electricity demand. There are a number of political, sociological, technical and economic obstacles that hinder the adoption of solar technologies. This chapter presents an optimization model that enables decision makers and professionals to study the economic feasibility of diffusing solar water heaters and photovoltaic systems.

## ECONOMIC BARRIERS OF SOLAR TECHNOLOGIES DIFFUSION WORLDWIDE

The economic barriers are considered to be a major obstacle to the deployment of solar technologies. Timilsina *et al.* [1] stated that one of the major economic barriers is the high initial cost of solar technologies in comparison with current conventional technologies. It is mentioned as well that financing solar technologies is a critical barrier as most of the financing institutions avoid supporting solar technologies as a result of its high economic risks and long payback periods. Other economic barriers include the increase in the costs of solar technologies basic materials such as copper used in solar water heating systems manufacturing. Chedid [2] argues that the main economic constraints that may prohibit achieving solar water heaters diffusion in Lebanon include lack of proper funding, lack of government support in terms of tax deductions and incentive programs and high initial cost of the systems. Timilsina *et al.* [3] stated that the main barrier to promoting solar technologies in Thailand is its high initial cost. Veeraboina and Ratnam [4] claimed that in India the challenges include the low prices of natural gas, insufficient financing mechanisms that support renewable technologies and high initial costs of green technologies. According to Mills and Schleich [5] high initial costs of the solar water heating systems, low incomes of households, and rental of houses instead of ownership are considered to be the main barriers in Greece. Faiers and Neame [6] indicated that solar technologies will not be able to compete with current conventional technologies unless the electricity prices increase or the solar technologies become cheaper and more efficient. Ndzibah [7] has highlighted that based on interviews conducted with citizens from various regions in Ghana, most Ghanaians consider solar energy the most suitable alternative that can replace conventional energy however they cannot afford it.

## POLICIES AND IMPLEMENTATION STRATEGIES

There are various policies that can support solar technologies. Timilsina *et al.* [1] mentioned different types of policies in their article “Solar Energy: Markets, Economics, and Policies” as follows: The feed in tariff (FIT) is suitable for all types of solar technologies. The renewable energy producers receive the cost of the energy generated in addition to their profits. It is claimed that the FIT can reduce the cost of renewable technologies as the potential renewable energy technologies guarantee long-term investments. The second policy is the investment tax credits which is an amount that can be deducted from the taxes paid by the tax payer in return of using solar energy technologies. Another policy is the renewable energy portfolio where governments set targets for percentages of the renewable energy supplied. To meet the targets energy producers and suppliers are required to provide certain percentages of renewable energy from the total amount of energy supplied. Suppliers who are not able to produce renewable energy can buy from suppliers who can. The net metering is a system that allows residential and commercial buildings to sell the extra solar energy they produce to the grid and this is implemented in Italy, Spain, Canada, USA and Australia. Another form of policies and solar technologies implementation strategies are the subsidies. Subsidies can be in terms of grants, soft loans, and capacity payments. In addition to the previous mandatory laws can force new construction and major renovation projects to use solar technologies. Finally, financing facilitation can be provided to support deployment of solar technologies. Timilsina *et al.* [3] mentioned that overcoming the economic obstacles of solar technologies can be implemented through Demand Side Management programs (DSM). Veerobina and Ratnam [4] have mentioned that the barriers of solar technologies adoption can be mitigated by developing suitable financial mechanisms consequently increase the demand of the renewable energy systems which can lead to a reduction in its costs. In addition to that the renewable technologies can be encouraged in poor and rural areas through government subsidies and innovative

## CHAPTER 9

# Heating Poultry Houses Using Renewable Energy

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**Abstract:** In broilers poultry house, fuel-based heating systems are commonly used to maintain the targeted temperatures for successful breeding of chicken. A considerable amount of fuel is consumed for this application, which leads to high running cost and contributes to the increase of air pollutant emissions. To investigate the economic feasibility of using solar energy as a substitute for the heating of poultry houses, a case study is conducted on a poultry broiler house located in El-Menia in Egypt. The location is selected based on the controversy foreseen due to the availability of high solar radiations versus the low fuel prices and absence of tax credits in Egypt. The case study includes the technical and economic study for a solar heating system (SHS) and the integration of biogas produced from chicken manure as an auxiliary source of heat. The heating demand is calculated hourly over a complete year using TRNSYS simulation tool. Accordingly, a SHS is designed to cover part of this demand besides a fuel based auxiliary source. The two main design variables of the SHS are the area of the solar collector and the volume of the storage tanks. An economical study of the SHS is carried out, where the net present value is calculated. The calculation is performed using the Egyptian and international fuel price.

**Keywords:** Bio-digesters, Biogas, Case study, Chicken manure, Economic study, Egypt, Energy, Fuel saver, Heating, Infiltration, Latent heat storage, Life cycle savings, Net present value, PCM, Poultry, Renewable, Simulation, Solar, Solar collectors, Storage tanks, Target temperature, TRNSYS.

## INTRODUCTION

Poultry cindustry is one of the energy intensive industries that consume large

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quantities of fuel, especially for the Broilers sector. Broiler poultry houses – producing chicken meat – heavily consume diesel fuel, gasoline or gas for their heating systems in order to maintain the temperatures required for the breeding of the chicks. The required temperature of any broiler house ranges from 22°C to 32°C depending on the birds' age. At each stage of the birds' development there is one optimum temperature zone in which the birds make the best performance in terms of the use of feed energy for growth and meat yield. If the birds are kept at a temperature that is lower than the targeted optimum temperature, the birds increase their feed intake and use more of the feed energy to keep their bodies' warm. This increases the production cost and decreases the meat yield. While, if kept at a temperature that is higher than the targeted optimum temperature, they reduce their feed intake to limit heat production. This also results in lower meat yield [1]. Therefore, an efficient heating system is necessary for any broiler house to maintain the required temperatures all around the year.

Currently, the heating systems used depend either on electricity, gas, diesel fuel, kerosene or other non-renewable sources. The equipment widely used in poultry houses are either direct hot air generators or indirect hot air generators-with external exhaust. The principle of operation of a hot air generator is having a pump that drives fuel under pressure to a burner nozzle. The fuel is sprayed into the combustion chamber, where it is burnt. The produced hot exhaust gases are used to heat an air stream that is supplied by a motor fan. The running cost of the aforementioned equipment is high and affects the economic efficiency of poultry houses.

In addition to its high running cost, conventional fuel-based heating systems contribute to the increase of air pollutant emissions. $CO_2$ emission is one of the main sources of global warming that the world is suffering. Globally, space heating and cooling systems consume 30–50% of global energy consumption, which is $5.6\times10^{10}$ MWh/year corresponding to the emission of $1.4\times10^{10}$ tons $CO_2$ per year [2]. A study made on the greenhouse gas emissions in EU countries showed that poultry produces 1.6 kg $CO_2$-eq per kg of chicken [3]. Clearly, the amount of $CO_2$ emitted per chicken varies from case to case depending on the amount of fuel used.

The amount of fuel used for heating a poultry house depends on many factors. One of the main factors is the climatic conditions [4]. The location of the house defines the annual mean air temperature and the lowest air temperatures reached during winter time, and thus determines the amount of space heating needed inside the house. Also, the level of insulation of the poultry house building indicates the amount of heat leakage to the outer atmosphere. Another factor affecting the amount of fuel used is the amount of heat produced by the chicken within the space to be heated. Chicken produce latent and sensible heat depending on their weight, age and brooding temperature [5]. Thus, the number of birds housed per volume and their weight affects the amount of heat needed to maintain a certain set temperature at this volume.

Many fields of research have been explored for utilizing different states of renewable energy including, geothermal, wind, solar and biomass energy. Solar energy is considered one of the most promising sources of renewable energy. The total annual solar radiation received on earth is approximately 3,400,000 EJ, which is tremendously greater than all other discovered and undiscovered non-renewable energy resources worldwide and is thousands of multiples of the world's total annual primary energy consumption of 450 EJ [6]. Being one of the most abundant sources of renewable energy, there is a great opportunity to utilize solar energy for space heating of poultry houses. Solar energy is extensively investigated worldwide to be used in different thermal applications such as solar water heaters, driers (air heaters), cookers, ponds, architecture, air-conditioning, chimneys and power plants [6]. Space heating of poultry houses can be achieved using the developed solar air or water heating techniques. However, it has to be noted that one of the main challenges of using solar energy is the energy storage method. Generally, for thermal energy storage, energy is stored by the change in the internal energy of a material by sensible heat, latent heat or thermo-chemical heat [7]. Sensible heat storage depends on raising the temperature of a certain material, whether solid or liquid, to utilize the heat capacity of this material. The amount of energy stored, $Q_S$, is determined by the specific heat of the material, $C_p$, the mass of the storage material, $m$, and change in temperature as shown in Equation (9-1)

# SUBJECT INDEX

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