

Solar Power in Building Design

The Engineer's Complete Design Resource

Peter Gevorkian

建筑设计中的太阳能技术应用
工程师设计资料集成





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Endorsements for *Solar Power in Building Design*

Dr. Peter Gevorkian's *Solar Power in Building Design* is the third book in a sequence of comprehensive surveys in the field of modern solar energy theory and practice. The technical title does little to betray to the reader (including the lay reader) the wonderful and uniquely entertaining immersion into the world of solar energy.

It is apparent to the reader, from the very first page, that the author is a master of the field and is weaving a story with a carefully designed plot. The author is a great storyteller and begins the book with a romantic yet rigorous historical perspective that includes the contribution of modern physics. A description of Einstein's photoelectric effect, which forms one of the foundations of current photovoltaic devices, sets the tone. We are then invited to witness the tense dialogue (the ac versus dc debate) between two giants in the field of electric energy, Edison and Tesla. The issues, though a century old, seem astonishingly fresh and relevant.

In the smoothest possible way Dr. Gevorkian escorts us in a well-rehearsed manner through a fascinating tour of the field of solar energy making stops to discuss the basic physics of the technology, manufacturing process, and detailed system design. Occasionally there is a delightful excursion into subjects such as energy conservation, building codes, and the practical side of project implementation.

All this would have been more than enough to satisfy the versed and unversed in the field of renewable energy. But as all masters, Dr. Gevorkian wraps up his textbook in relevance by including a thorough discussion of the current solar initiatives (California being a prototype) and the spectrum of programs and financial incentives that are being created.

Solar Power in Building Design has the seductive quality of being at once an overview and course in solar energy for anyone with or without a technical background. I suspect that this book will likely become a standard reference for all who engage in the emerging renewable energy field.

DR. DANNY PETRASEK, M.D., PH.D.
California Institute of Technology

Dr. Gevorkian's *Solar Power in Building Design* is a great read. If you are able to envision a relatively arcane subject such as solar energy and photovoltaic applications as a compelling, page-turning read, this is your book.

Dr. Gevorkian is a very lucid writer. A dedicated grammarian as well as a master of a multiplicity of scientific disciplines, Dr. Gevorkian has crafted a text that broadens even the most jaded reader's perspective on the subject of solar power. He ranges from storytelling, as with his brief characterization of the controversy between early innovators Nikolai Tesla and Thomas Edison in the pioneering years of the modern Energy Age, to a full-blown historical tracing of the rapid advances of the expansive diversification of energy applications within the past 50 years.

Throughout the book, Dr. Gevorkian espouses a didactic approach that is thoroughly inductive. A wide swath of information, integral to the exposition of the text, is presented in survey fashion. Many questions are both asked and answered, which provides any level of audience with a great deal of satisfaction as they pour over the wide variety of data needed to complete this intriguing story.

Very little of this complex domain is left to speculation. The layperson drawn to this subject matter should be appreciative, as Dr. Gevorkian prepares any reader to be able to intelligently communicate with a consultant hired to install a solar power system, or to even install a system themselves.

Myriad examples of the range of installations, replete with visual support in the form of graphs, charts, renderings, and color photographs, serve to provide even the most technically inept audience with the

The wealth of information and the abundance of resources contained in this volume will establish it as an encyclopedia for solar energy design.

Congratulation for a great landmark work! Save our planet! Keep it green!

EMILY LUK, M.D.

Dr. Gevorkian's *Solar Power in Building Design* is a very well written, scientifically sound, and technologically proficient book that should appeal to scientists, engineers, technologists, technicians, and laypersons alike. It is written in a simple, easy-to-read, and straightforward style that introduces the theory and then delves, immediately, into the practicalities. It is also replete with suitable illustrations. Energy is crucial for economic growth, but, as it now exists, extracts a heavy price in terms of environmental degradation. Solar energy offers an attractive mitigation here, albeit partially. But then, in an age of almost universal concerns about energy and environment, the fact is that a wide gulf separates our awareness of the need to use solar power and our familiarity with the nuts and bolts of harnessing this power. Dr. Gevorkian's book bridges that and can therefore be as much a resource for the solar energy professionals as for the solar energy enthusiasts as well as curious onlookers.

DR. PAL POORNA, M.S., M.B.A., PH.D.

Chair

Physical Science

Glendale Community College

Glendale, CA

It is an honor to be asked to review your latest book *Solar Power in Building Design*.

This book is systematically and simply presented to acquaint any student with the procedures necessary to incorporate solar power in the design of buildings.

The book covers straightforward delineation from basic physics through technologies, design, and implementation and culminates in an appreciation of our environment, and diminishing our dependence on fossil fuels, while punctuating the ultimate economics involved in preserving our planet.

The capturing of solar energy has been around for a long time, and educating the people of this planet as to how to utilize this natural resource remains a paramount task. This book is essentially a comprehensive educational resource and a design reference manual that offers the reader an opportunity to learn about the entire spectrum of solar power technology with remarkable ease. The book is a magnificent accomplishment.

WILLIAM NONA

Architect

National Council of Architectural Registration Boards

The author has provided very comprehensive material in the field of photovoltaic and solar systems in the text, starting from the basic knowledge on silicon technology, solar cell processing, and module manufacturing to the cutting edge and most aesthetically pleasing BIPV (building-integration photovoltaic) systems and installations. The content given has all the necessary tools and information to optimize solar system designs and integration. To all professionals interested in having a thorough knowledge in photovoltaic systems design, integration, and engineering, this book is a must.

FRANK C. PAO

Chairman Atlantis Energy Systems, Inc.

certainty that they can adeptly navigate their way around a solar power system. That is the true beauty of *Solar Power in Building Design*: a gem of a book for even armchair wannabe experts.

DR. LANCE WILLIAMS
Executive Director
US Green Building Council
Los Angeles chapter

I think the best way to summarize *Solar Power in Building Design* is “more than you thought you needed to know.” Dr. Gevorkian has covered many areas of the solar power design in a manner that allows the reader to really have a remarkable, practical understanding of solar renewable energy as it now exists in North America. Anyone getting into the business should really consider this book as a “must read,” a super primer for a thorough understanding of the industry. In addition to covering the historical perspective, the book reflects a fresh perspective of the future direction of where the industry will be in 25 years.

In addition to magnificent coverage of technology issues, the reader is introduced to the critical underlying intricacies of capital assets management such as long functioning life and specificity of unique factors that must be taken into account for financial analysis. In addition the book skillfully covers asset profiling economics for the present and future and reflects a unique perspective as to how solar power cogeneration fits into the energy needs of the future.

Congratulations for another fine scholarly work!

GENE BECK
President
EnviroTech Financial, Inc.

I have never before enjoyed reading a technology book that could deliver so much information down to the core without once becoming boring and complicated.

The book takes the reader through the challenges of solar energy technology, engineering, and design and its applications, providing every detail and an in-depth perspective from the basic to the most complex issues.

Although it has been written for solar energy professionals, this book is a resource for anyone interested in solar energy technologies as Dr. Gevorkian has described the concepts of solar power engineering and design precisely and clearly.

The highly informative diagrams and illustrations with each chapter help in understanding the dynamics of solar power.

I also strongly recommend *Solar Power in Building Design* as a standard curriculum and guide on renewable energy for architectural and engineering schools and colleges as a resource for students.

DR. FARHAT IQBAL
President
Silica Solar LLC

The passion of the author in preservation of our ecological system, and in renewable energy in particular, is obvious in the pages of this scholarly text. His knowledge in the subject matter of solar energy is evidenced in the clear presentation that can be understood by the general populace, yet technological experts will appreciate the in-depth discussions.

Solar Power in Building Design is a comprehensive solar power design reference resource and timely educational book for our planet's troubled times. With global warming, pollution, and the waste of energy showing their irreparable damage, Dr. Peter Gevorkian's book is pioneering in the field of solar power cogeneration and fills a significant technology educational void sorely needed to mitigate our present environmental pollution. Dr. Gevorkian explains difficult technical concepts with such ease that it becomes a pleasure to read the entire book. It is truly remarkable how the detailed explanation of each process facilitates the conveyance of knowledge from a scientific source to a nontechnical reader.

EDWARD ALEXANIANS, S.E.

Sr. Engineer

Los Angeles County Research Engineering Department

Solar Power in Building Design is the comprehensive reference manual on solar power systems. This is a must read for anyone who will be implementing a solar power system from small residential applications to large commercial or industrial applications. This book has everything from the theory of solar power generation, to design guidelines, to the economics of solar systems. The field of solar power generation is advancing very quickly; however, this book includes the most current technology available and also includes emerging research and trends that provide a view of the future in solar power systems.

STEVE S. HIRAI, P.E.

Principal Engineer

Montgomery Watson Americas

Solar Power in Building Design is a remarkably comprehensive and easy-to-read book on solar power technology. The book as a design reference manual is very timely, relevant, and informative and exposes the reader to the entire spectrum of solar power technology as a whole. The most remarkable attribute of the book is that it can be read and understood by anyone without previous knowledge of the subject.

GUADALUPE FLORES, AIA

President

Pasadena and Foothill AIA Chapter

Dr. Peter Gevorkian's latest in a series of three books on sustainable energy truly hits the mark as the *ultimate* go-to guide for anything and everything quite literally "under the sun" relating to making use of this vital resource—solar energy.

In a text that is immediately engaging and understandable to anyone with the need or desire to expand knowledge in this vital technology, Dr Gevorkian reveals that harnessing sunlight into a practical energy source is doable in the here and now. Charts, graphs, photos, and illustrations are deftly used to support the vital concepts he explains so clearly. Everything you could possibly need, from conceptual presentation to a client, to site evaluation, to the nuts and bolts of components and installation methods are found here. Additionally, the text explains the historical development of the technologies and components from which today's products are derived.

MARY KANIAN

Environmentalist

Solar Power in Building Design is a must-read primer for any professional or professional-to-be, who wants to learn about challenges and opportunities associated with design implementation or economics of solar systems.

The author emphasizes how engineering design is impacted by economics, environment, and local government policies.

The book precisely shows the current state of solar and renewable energy technology, its challenges, and its up-to-date successes.

Trivia facts and history of solar technology make this book fun to read.

ANDRZEJ KROL, P.E.
President
California Electrical Services
Glendale, CA

Producing electricity from the sun using photovoltaic (PV) systems or solar thermal systems for heating and cooling has become a major industry worldwide along with many helpful multilingual solar system simulation software tools. But engineering, installing, monitoring, and maintaining such systems requires constant knowledge update and ongoing training.

Dr. Gevorkian's *Solar Power in Building Design* makes a superb reference guide on solar electricity and offers a unique combination of technical and holistic discussion on building rating systems such as LEED with practical advice for students, professionals, and investors.

Well-illustrated chapter sequences with built U.S. examples offer step-by-step insights on the theory and reality of installed renewable energy systems, solar site analysis, component specifications, and U.S.-specific system costs and economics, performance, and monitoring.

THOMAS SPIEGELHALTER
Professor
School of Architecture
University of Southern California
R.A. EU, ISES, LEED
Freiburg, Germany, and Los Angeles

Solar Power in Building Design is a comprehensive book that is an indispensable reference for students and professionals.

Each of the topics is presented completely, with clear and concise text. A history of each subject is followed by both a global and a detailed view. The invaluable historical background amazingly spans topics as diverse as the centuries-old Baghdad battery to the photoelectric effect.

The figures in the text are excellent: the diagrams and illustrations, with the accompanying text in the book, walk the reader through each section, resulting in a better understanding of the concepts presented. The photographs are also excellent in that they clearly show their intended subject. In addition, the author has clearly thought through each topic, ensuring that there are no surprises for the professional embarking on incorporating a solar power system into a building's design.

DR. VAHE PEROOMIAN, PH.D.
Professor of Physics
University of California (UCLA)

SOLAR POWER IN BUILDING DESIGN

THE ENGINEER'S COMPLETE DESIGN RESOURCE

PETER GEVORKIAN, PH.D., P.E.



New York Chicago San Francisco Lisbon London Madrid
Mexico City Milan New Delhi San Juan Seoul
Singapore Sydney Toronto

Eons ago humans cowered from the sun fearing its power as a malevolent God.

Those who learned its rhythms became shaman, bringing the knowledge of the seasons to their people. By the end of the twentieth century humankind had harnessed much energy originally derived from the sun, and buildings sheltered rather than celebrated natural forces.

The twenty-first century brings new opportunities to choose alternative energy sources—or actually those that were always there. Dr. Gevorkian is a modern-day shaman. In a world where wars are fought for dinosaur remains, located deep in the earth, Dr. Gevorkian enlightens us on how to pluck energy from the sky.

Like a magician who has revealed all his secrets, *Solar Power in Building Design* is the definitive Manual for just that. Between its covers are all the answers for the application of solar power. If one had to grab just one book on solar energy prior to ducking into the bomb shelter, I would go for this one.

MARK GANGI, AIA
Principle
Gangi Architects

INTRODUCTION

Since the dawn of agriculture and civilization, human beings have hastened deforestation, impacting climatic and ecological conditions. Deforestation and the use of fossil fuel energy diminish the natural recycling of carbon dioxide gases. This accelerates and increases the inversion layer that traps the reflected energy of the sun. The augmented inversion layer has an elevated atmospheric temperature, giving rise to global warming, which in turn has caused melting of the polar ice, substantial changes to climatic conditions, and depletion of the ozone layer.

Within a couple of centuries, the unchecked effects of global warming will not only change the makeup of the global land mass but will affect human's lifestyle on the planet.

Continued melting of the polar ice caps will increase seawater levels and will gradually cover some habitable areas of global shorelines. It will also result in unpredictable climatic changes, such as unusual precipitation, floods, hurricanes, and tornadoes.

In view of the rapid expansion of the world's economies, particularly those of developing countries with large populations, such as China and India, demand for fossil fuel and construction materials will become severe. Within the next few decades, if continued at the present projected pace, the excessive demand for fossil fuel energy resources, such as crude oil, natural gas, and coal, will result in the demise of the ecology of our planet and, if not mitigated, may be irreversible. Today China's enormous demand for energy and construction materials has resulted in considerable cost escalations of crude oil, construction steel, and lumber, all of which require the expenditure of fossil fuel energy.

Developing countries are the most efficient consumers of energy, since every scrap of material, paper, plastic, metal cans, rubber, and even common trash, is recycled and reused. However, when the 2.3 billion combined populations of China and India attain a higher margin of families with middle-class incomes, the new demand for electricity, manufacturing, and millions of automobiles will undoubtedly change the balance of ecological and social stability to a level beyond imagination.

The United States is the richest country in the world. With 5 percent of the world's population, the country consumes 25 percent of the global aggregate energy. As a result of its economic power, the United States enjoys one of the highest standards of living with the best medical care and human longevity. The relative affluence of the country as a whole has resulted in the cheapest cost of energy and its wastage.

Most consumption of fossil fuel energy is a result of inefficient and wasteful transportation and electric power generation technologies. Because of the lack of comprehensive energy control policies and lobbying efforts of special-interest groups, research and development funds to accelerate sustainable and renewable energy technologies have been neglected.

In order to curb the waste of fossil fuel energy, it is imperative that our nation, as a whole, from politicians and educators to the general public, be made aware of the dire consequences of our nation's energy policies and make every effort to promote the use of all available renewable energy technologies so that we can reduce the demand for nonrenewable energy and safeguard the environment for future generations.

The deterioration of our planet's ecosystem and atmosphere cannot be ignored or considered a matter that is not of immediate concern. Our planet's ozone layer according to scientists has been depleted by about 40 percent over the past century and greenhouse gases have altered meteorological conditions. Unfortunately, the collective social consciousness of the educated masses of our society has not concerned itself with the disaster awaiting our future generations and continues to ignore the seriousness of the situation.

About This Book

During years of practice as a research and design engineer, I have come to realize that the best way to promote the use of solar power as a sustainable energy design is to properly educate key professionals, such as architects, engineers, and program managers whose opinions direct project development.

I have found that even though solar power at present is a relatively mature technology, its use and application in the building industry is hampered due to lack of exposure and education. Regardless of present federal and state incentive programs, sustainable design by use of renewable energy will not be possible without a fundamental change in the way we educate our architects, engineers, and decision makers.

In two earlier books titled *Sustainable Energy Systems in Architectural Design* and *Sustainable Energy Systems Engineering*, I attempted to introduce architects, engineers, and scientists to a number of prevailing renewable energy technologies and their practical use, in the hopes that a measure of familiarity and understanding could perhaps encourage their deployment.

This book has been specifically written to serve as a pragmatic design resource for solar photovoltaic power systems engineering. When writing the manuscript, I attempted to minimize unnecessary mathematics and related theoretical photovoltaic physics, by only covering real-life, straightforward design techniques that are commonly practiced in the industry.

As scientists, engineers, and architects, we have throughout the last few centuries been responsible for the elevation of human living standards and contributed to advancements in technology. We have succeeded in putting a human on the moon, while ignoring the devastating side effects to the global ecology. In the process of creating the betterment and comforts of life, we have tapped into the most precious nonrenewable energy resources, miraculously created over the life span of our planet, and have been misusing them in a wasteful manner to satisfy our most rudimentary energy needs.

Before it is too late, as responsible citizens of our global village, it is high time that we assume individual and collective responsibility to resolve today's environmental issues and ensure that future life on Earth will continue to exist as nature intended.

Global Warming and Climate Change

Ever since the industrial revolution, human activities have constantly changed the natural composition of Earth's atmosphere. Concentrations of trace atmospheric gases, nowadays termed "greenhouse gases," are increasing at an alarming rate. There is conclusive evidence that the consumption of fossil fuels, conversion of forests to agricultural land, and the emission of industrial chemicals are principal contributing factors to air pollution.

According to the National Academy of Sciences, Earth's surface temperature has risen by about one degree Fahrenheit (°F) in the past century, with accelerated warming occurring in the past three decades. According to statistical review of the atmospheric and climatic records, there is substantial evidence that global warming over the past 50 years is directly attributable to human activities.

Under normal atmospheric conditions, energy from the sun controls Earth's weather and climate patterns. Heating of Earth's surface resulting from the sun radiates energy back into space. Atmospheric greenhouse gases, including carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), tropospheric ozone (O₃), and water vapor (H₂O) trap some of this outgoing energy, retaining it in the form of heat, somewhat like a glass dome. This is referred to as the *greenhouse effect*.

Without the greenhouse effect, surface temperatures on Earth would be roughly 30°C [54 degrees Fahrenheit (°F)] colder than they are today—too cold to support life. Reducing greenhouse gas emissions depends on reducing the amount of fossil fuel-fired energy that we produce and consume.

Fossil fuels include coal, petroleum, and natural gas, all of which are used to fuel electric power generation and transportation. Substantial increases in the use of non-renewable fuels is a principal factor in the rapid increase in global greenhouse gas emissions. The use of renewable fuels can be extended to power industrial, commercial, residential, and transportation applications to substantially reduce air pollution.

Examples of zero-emission, renewable fuels include solar, wind, geothermal, and renewably powered fuel cells. These fuel types, in combination with advances in energy-efficient equipment design and sophisticated energy management techniques, can reduce the risk of climate change and the resulting harmful effects on the ecology. Keep in mind that natural greenhouse gases are a necessary part of sustaining life on Earth. It is the anthropogenic or human-caused increase in greenhouse gases that is of concern to the international scientific community and governments around the world.

Since the beginning of the modern industrial revolution, atmospheric concentrations of carbon dioxide have increased by nearly 30 percent, methane concentrations have more than doubled, and nitrous oxide concentrations have also risen by about 15 percent. These increases in greenhouse gas emissions have enhanced the heat-trapping capability of Earth's atmosphere.

Fossil fuels burned to operate electric power plants, run cars and trucks, and heat homes and businesses are responsible for about 98 percent of U.S. carbon dioxide emissions, 24 percent of U.S. methane emissions, and 18 percent of U.S. nitrous oxide

emissions. Increased deforestation, landfills, large agricultural production, industrial production, and mining also contribute a significant share of emissions. In 2000, the United States produced about 25 percent of total global greenhouse gas emissions, the largest contributing country in the world.

Estimating future emissions depends on demographics, economics, technological policies, and institutional developments. Several emissions scenarios have been developed based on differing projections of these underlying factors. It is estimated that by the year 2100, in the absence of emission-control policies, carbon dioxide concentrations will be about 30 to 150 percent higher than today's levels.

Increasing concentrations of greenhouse gases are expected to accelerate global climate change. Scientists expect that the average global surface temperatures could rise an additional 1°F to 4.5°F within the next 50 years and 2.2°F to 10°F over the next century, with significant regional variation. Records show that the 10 warmest years of the twentieth century all occurred in the last 15 years of that century. The expected impacts of this weather warming trend include the following:

Water resources. A warming-induced decrease in mountain snowpack storage will increase winter stream flows (and flooding) and decrease summer flows. This along with an increased evapotranspiration rate is likely to cause a decrease in water deliveries.

Agriculture. The agricultural industry will be adversely affected by lower water supplies and increased weather variability, including extreme heat and drought.

Forestry. An increase in summer heat and dryness is likely to result in forest fires, an increase in insect populations, and disease.

Electric energy. Increased summer heat is likely to cause an increase in the demand for electricity due to an increased reliance on air conditioning. Reduced snowpack is likely to decrease the availability of hydroelectric supplies.

Regional air quality and human health. Higher temperatures may worsen existing air quality problems, particularly if there is a greater reliance on fossil fuel generated electricity. Higher heat would also increase health risks for some segments of the population.

Rising ocean levels. Thermal expansion of the ocean and glacial melting are likely to cause a 0.5 to 1.5 m (2 to 4 ft) rise in ocean levels by 2100.

Natural habitat. Rising ocean levels and reduced summer river flow are likely to reduce coastal and wetland habitats. These changes could also adversely affect spawning fish populations. A general increase in temperatures and accompanying increases in summer dryness could also adversely affect wildland plant and animal species.

Scientists calculate that without considering feedback mechanisms a doubling of carbon dioxide would lead to a global temperature increase of 1.2°C (2.2°F). But, the net effect of positive and negative feedback patterns would cause substantially more warming than would the change in greenhouse gases alone.

Pollution Abatement Consideration

According to a 1999 study report by the U.S. Department of Energy (DOE), one kilowatt of energy produced by a coal-fired electric power-generating plant requires about 5 pound (lb) of coal. Likewise, generation of 1.5 kilowatt-hours (kWh) of electric energy per year requires about 7400 lb of coal that in turn produces 10,000 lb of carbon dioxide (CO₂).

Roughly speaking, the calculated projection of the power demand for the project totals to about 2500 to 3000 kWh. This will require between 12 million and 15 million lb of coal, thereby producing about 16 million to 200 million lb of carbon dioxide. Solar power, if implemented as previously discussed, will substantially minimize the air pollution index. The Environmental Protection Agency (EPA) will soon be instituting an air pollution indexing system that will be factored into all future construction permits. All major industrial projects will be required to meet and adhere to the air pollution standards and offset excess energy consumption by means of solar or renewable energy resources.

Energy Escalation Cost Projection

According to the Energy Information Administration data source published in 1999, California consumes just as much energy as Brazil or the United Kingdom. The entire global crude oil reserves are estimated to last about 30 to 80 years, and over 50 percent of the nation's energy is imported from abroad. It is inevitable that energy costs will surpass historical cost escalations averaging projections. The growth of fossil fuel consumption is illustrated in Figure I.1. It is estimated that the cost of nonrenewable energy will, within the next decade, increase by approximately 4 to 5 percent by producers.

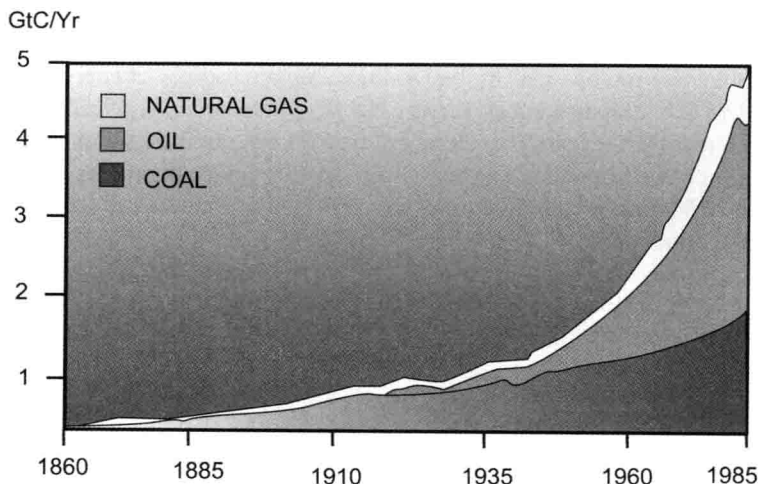


Figure I.1 Growth in fossil fuel consumption. *Courtesy of Geothermal Education Office.*

When compounded with a general inflation rate of 3 percent, the average energy cost increase, over the next decade, could be expected to rise at a rate of about 7 percent per year. This cost increase does not take into account other inflation factors, such as regional conflicts, embargoes, and natural catastrophes.

Solar power cogeneration systems require nearly zero maintenance and are more reliable than any human-made power generation devices. The systems have an actual life span of 35 to 40 years and are guaranteed by the manufacturers for a period of 25 years. It is my opinion that in a near-perfect geographic setting, the integration of the systems into the mainstream of architectural design will not only enhance the design aesthetics but also will generate considerable savings and mitigate adverse effects on the ecology and global warming.

Social and Environmental Concerns

Nowadays, we do not think twice about leaving lights on or turning off the television or computers, which run for hours. Most people believe that energy seems infinite, but in fact, that is not the case. World consumption of fossil fuels, which supply us with most of our energy, is steadily rising. In 1999, it was found that out of 97 quads of energy used (a quad is 3×10^{11} kWh) 80 quads came from coal, oil, and natural gas. As we know, sources of fossil fuels will undoubtedly run out within a few generations and the world has to be ready with alternative and new sources of energy. In reality, as early as 2020, we could be having some serious energy deficiencies. Therefore, interest in renewable fuels such as wind, solar, hydropower, and others is a hot topic among many people.

Renewable fuels are not a new phenomenon, although they may seem so. In fact, the industrial revolution was launched with renewable fuels. The United States and the world has, for a long time, been using energy without serious concern, until the 1973 and 1974 energy conferences, when the energy conservation issues were brought to the attention of the industrialized world. Ever since, we were forced to realize that the supply of fossil fuels would one day run out, and we had to find alternate sources of energy.

In 1999, the U.S. Department of Energy (DOE) published a large report in which it was disclosed that by the year 2020 there will be a 60 percent increase in carbon dioxide emissions which will create a serious strain on the environment, as it will further aggravate the dilemma with greenhouse gases. Figure I.2 shows the growth of carbon dioxide in the atmosphere.

A simple solution may seem to be to reduce energy consumption; however, it would not be feasible. It has been found that there is a correlation between high electricity consumption (4000 kWh per capita) and a high Human Development Index (HDI), which measures quality of life.

In other words there is a direct correlation between quality of life and the amount of energy used. This is one of the reasons that our standard of living in the industrialized countries is better than in third-world countries, where there is very little access to electricity. In 1999, the United States had 5 percent of the world's population and produced 30 percent of the gross world product. We also consumed 25 percent of the world's energy and emitted 25 percent of the carbon dioxide.