FUNDAMENTALS OF SOLAR HEATING

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PREFACE

In the year 1973, 73 quads of energy were used in the United States. In 1980 that energy consumption increased to 90 quads. It is estimated that by the year 2000 the energy requirement will be about 178 quads. A quad of energy is 1 quadrillion BTU's, or 1,000,000,000,000,000 BTU's. A BTU, the British Thermal Unit, is the energy required to raise 1 pound of water 1 degree Fahrenheit. In more familiar terms, the energy equivalent of 90 quads is 15 billion barrels of oil. Needless to say, numbers of this magnitude have little significance to most of us except that they seem big. Of the energy produced in 1980, approximately 98% came from oil, gas, coal, and nuclear fuels—all of which are non-renewable resources. Not only are the fuels of the 1980's non-renewable, but their effect on the environment is presently in debate with evidence of carbon, nitrous, and sulfur dioxides in the air along with resulting acid rains.

Renewable resources, as an alternate source of energy, have come into focus in recent times. The most familiar are wind, wood, solar, alcohol, and methane. Of these, the most abundant, least polluting, and most competitive with fossil fuels are the active and/or passive solar collector systems. As an example, plant life converts solar energy into a concentrated energy form at an efficiency of about 2% through the process of photosynthesis. In order to release this energy into a useful form, it must be burned. The side effect involves introducing into the atmosphere the undesirable carbon dioxides, carbon monoxides, sulfur oxides, hydrocarbons, nitrogen oxides, and solid particles. On the other hand, a solar collector system can direct 50% of the energy from the sun into a useful form such as residential, commercial and industrial space heating, water heating, air conditioning, and so forth. A significant consideration is that the direct solar conversion of energy introduces no pollutants into the atmosphere in the case of passive solar systems, and very few (about 4% as much when compared to fossil fuels) for active systems.

The use of solar conversion systems has virtually been non-existent in the past because of the abundance and inexpensive cost of fossil fuels. By the most optimistic estimates the life expectancy of the oil-gas era is eighty years, with increasing pressure on cost as a result of scarcity. As energy costs increase, the solar conversion system looks more attractive.

One opposition to the use of solar conversion systems has been the massive structure required to obtain a significant amount of energy. Solar energy is abundant but not concentrated, as is oil, gas, coal, and nuclear fuels. How massive a structure would be required to supply all the energy needs of the United States in the year 2000 when 178 quads of energy are required? Using an average incoming energy value of 200 W/m^2 and an efficiency of 50%, the required horizontal collector area would be 22,000 square miles, or a square of about 150 miles on the side. This compares with 3.8 million square miles for the 48 contiguous states, or about 6/10 of one percent of the land mass. Although solar systems are large, they do not represent a disproportionate area when compared to the available land.

This book addresses itself to the fundamental understanding of solar energy and its practical applications. It concentrates on residential space and hot water heating, although the principles apply to commercial and industrial applications as well. Chapter 1 covers some historical background of the energy field relating it to the quality of living we experience today. In Chapter 2 the economics of alternate energy is explored. The authors felt that if a form of alternate energy is not cost-effective, then it is unnecessary to proceed, hence, the early introduction of economics. Chapter 3 gives thermodynamics background for the student, some of which is simplified and some more detailed. In chapter 4, solar insolation and all its ramifications are presented. Chapter 5 presents two methods of determining heat losses for a building, by using the fuel bill and by using classical heat loss method.

Chapter 6 explores the characteristics of flat-plate collectors, including observations by the authors through classroom modeling and full size prototype construction. Current testing procedures are outlined. Chapters 7, 8, and 9 discuss the storage, distribution, and controls required to complete a fully operational solar system. In Chapter 10, applications of solar systems, including the proper sizing of ductwork, are outlined. Passive system design

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parameters, based on experience, are given. Swimming pool design is discussed in Chapter 11 while Chapter 12 lists the SOLRAD program along with typical output data. The appendices include additional solar insolation data along with geographical sunshine and degree-day information. A manufacturer's catalogue is included.

Richard C. Schubert
L. D. Ryan

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INTRODUCTION

1.1 ENERGY AND MAN

"The optimist proclaims that we live in the best of all possible worlds, and the pessimist fears this is true" [1].

Energy is vital to life. The processes of the body depend directly upon energy. Energy from the sun is converted to store chemical energy in plants and animals. These foods become the source of power that provides muscle power, body warmth, and the maintenance of life. Man is a solar-powered system.

A certain number of human beings can exist in harmony with the energy environment. The energy environment is the total available fossil-fuel reserves, the annual food production, nuclear fuels, and alternative energy sources. These alternative energy sources are actually direct or indirect uses of solar energy. Solar panels, wind generators, methane digesters, and water-wave generators are examples of direct and indirect solar sources. There is a population balance that would allow harmony between human beings and their demands for energy. Ideally, fossil fuels should be used only to balance demand variation that could not be met with a renewable resource. Because of the initial abundance of fossil fuel, little attention was given to the process of destroying an energy source that is practically nonrenewable. Energy cannot be destroyed, but it does become unavailable for use.

Today's population levels of the earth are supported to a great extent by fossil-fuel reserves. The fossil-fuel reserves were built through the ages

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by capturing solar energy in plants. Mechanized agriculture, transportation, health care, and manufacturing are activities that support life. These endeavors depend heavily upon fossil fuels.

Depletion of fossil fuels would directly affect the number of individuals that could survive on this planet. The available fossil-fuel and the population distribution must move together unless shifts are made to renewable resources. Energy manipulation to increase productivity of life's essentials has allowed the population to increase to its present level. Food surpluses can produce large populations. Large populations can produce complex political and social problems.

Basically, people have never had a strategy for successful use and control of their environment. Each generation must start anew and relearn all the lessons of the past. History has proven to be a very poor instructor. Whether the species is comprised of rabbits or *Homo sapiens*, they will multiply to the maximum, and as long as earth supports minimum needs, population levels will increase.

The discovery of America gave Europe, which was overcrowded with insufficient resources, a second chance. The poorhouses of Europe dumped their human cargoes onto the virgin lands of America. The returning ships brought back much needed resources, such as lumber and fur. Two important things were happening to Europe. Population was declining by export and precious resources were increasing by import. The discovery of America coupled with technological advances purchased time for Western civilization.

The advent of the space age gave new hope. Perhaps there was another America somewhere in outer space. A place where ghettos could be emptied onto a new land and needed resources could be brought back on the return trip. A place where energetic young persons could go and seek their fortunes. American astronauts on the moon looked back at our lonely spaceship earth and realized the finiteness of the human being. There is no compatible America in outer space that we can reach in a human lifetime. The earth is home forever.

1.2 ENERGY USE INCREASES

Energy use per capita has increased steadily since the depression of the 1930s. Throughout the world, energy consumption has increased at an alarming rate. Annual energy consumptions for various countries are listed in Table 1-1.

Almost all experts agree that it is very probable that the end of the fossil-fuel era is in sight. Accelerated usage and population growth have seriously aggravated a worsening situation. An accurate prediction of the end of the fossil-fuel era is practically impossible. Published data on energy consumption per capita and estimated fuel reserves vary considerably. Extrapolation

TABLE 1-1 Annual Energy Consumption, by Country (Btu/person)

Country	1968	1971	Percent of Increase
United States	312×10^6	337×10^6	8.1
Great Britain	148.7×10^6	165×10^6	11.0
West Germany	134.5×10^6	156.5×10^6	16.4
USSR	121.4×10^6	136×10^6	12.0
France	98×10^6	117×10^6	19.7
Japan	75.5×10^6	98×10^6	29.7
Remainder of world	52×10^6	58×10^6	11.1

of today's demand to the future often neglects the effects of pricing and conservation; yet the problem is clearly identified. *There is a developing energy shortage that will cause economic collapse and mass starvation*, and this terrifying situation will be upon mankind long before fossil fuels are completely exhausted.

There appear to be obvious solutions that could come about naturally in a free market. As demand increases and supplies dwindle, prices will rise. Increased prices would cause conservation and make alternative energy sources more competitive with fossil fuels. The difficulty is that much of the world has little faith in the free-market system, and therefore governmental manipulation to solve various problems often stops the natural process from functioning. Price controls on fuel and payment of heating bills by the government are examples of negative solutions to an energy crisis. History has verified that governments often cause more problems than they solve.

1.3 ENERGY VERSUS THE GROSS NATIONAL PRODUCT

How, then, shall we live? The United States could practically solve its energy crisis, at least for a number of years, through conservation. If the United States would approach Japan's energy consumption, over 70 percent of our total energy demand would be eliminated. Extensive use of railroads would reduce our energy appetite for transportation by 25%. High crime rates, superhighways, truckers, and American independence make this transition a challenge.

Extensive changes in our purchasing attitude would promote conservation. If quality were a prime factor in product purchases, less energy would be required. Presently, low-cost consumer items are produced because the market demands junk. Model changes, new styles, and throwaway items accelerate energy needs. A very simplified schematic of this cycle is shown in Figure 1-1.

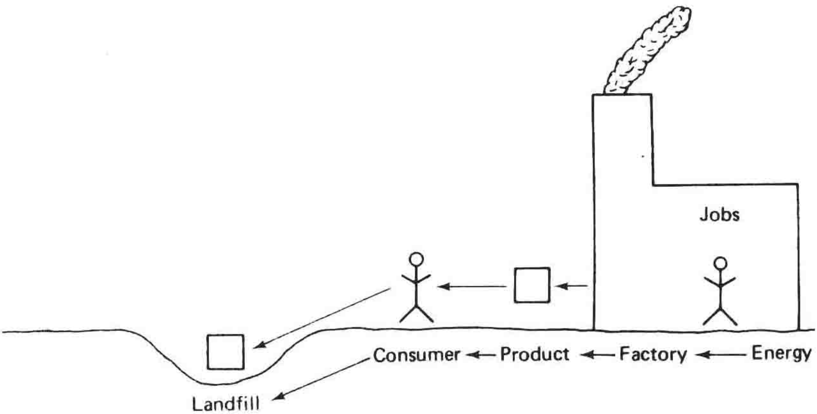

Figure 1-1. The consumer ⟶ waste cycle.

High-quality automobiles that last twice as long at twice the price are technically possible. The energy used to produce quality is comparable to energy used on the economy models. The end result would be energy conservation.

Our present economy is dependent upon energy consumption. It appears that the gross national product (GNP) is directly proportional to the energy consumed. The GNP has been an indication of prosperity, and prosperity is assumed to be related to a quality of life. In reality, the prosperous often seek the simpler life, and with little exception, the GNP (the sum of all the goods and services) has very little to do with the quality of life. In Figure 1-2 energy consumption versus the GNP of various countries is shown.

The dilemma is apparent. Conservation could destroy our economy, yet conservation is mandatory. Alternative energy sources require extensive conservation to be successful. Present demands on fossil fuel also make conservation mandatory. In any event, conservation is needed and will eventually happen naturally.

The developing solar energy industry will provide jobs. It is questionable if anything can or should be done to maintain the present economic lifestyle. Change is necessary and morally imperative. The desire to escape drudgery has produced gadgetry that consumes energy to operate and to produce. Future generations will be denied their fair share of fossil fuels because of nonsensical attitudes of today about being modern.

Centralization, high-speed travel, controlling crime with lighting, riding lawn mowers, and throwaway containers are a few of the obvious "advances" that must be reversed.

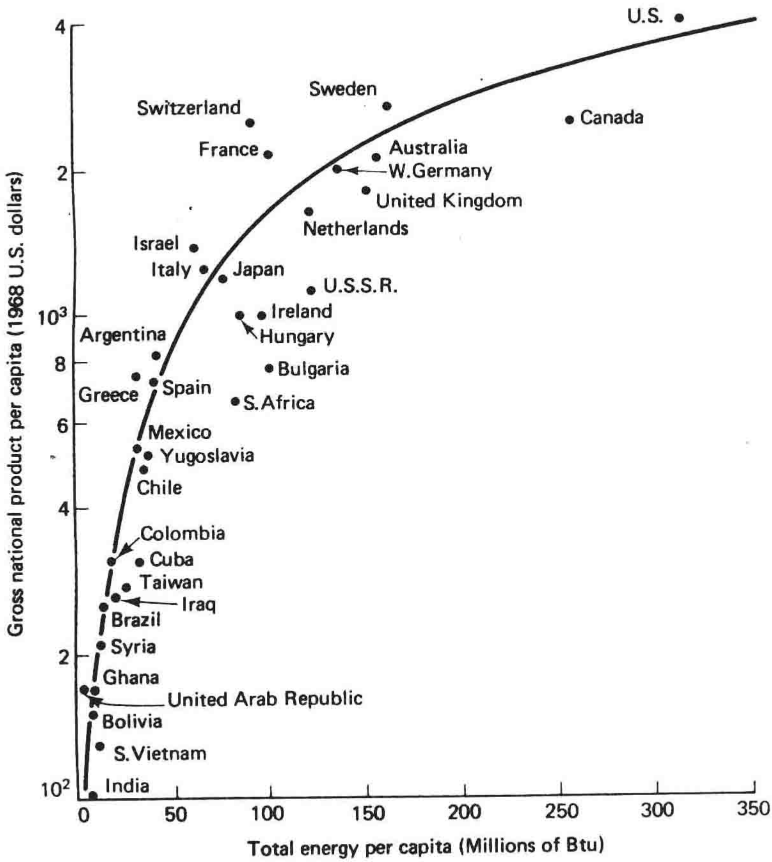

Figure 1-2. Energy use per capita versus the gross national product per capita in 1968 for several nations.

1.4 WHY SOLAR?

There are many sources of energy available. Each should be carefully considered. For an energy source to be classified as *appropriate*, several criteria must be satisfied. Is the source potentially harmful to the environment? Is the source an asset to national defense? Is the source renewable? Nuclear fission power fails in all three cases. Centralized fossil-fuel power plants fail in all three cases. Solar energy meets each requirement.

The sun's power produces radiant energy that can be used directly. The radiation can be converted to electricity through a photovoltaic cell. The technological "know-how" is available. The basic problem is cost. Today it costs $30 to $50 per peak watt of rated capacity to produce electricity directly from the sun through photovoltaic cells. If a 100-watt bulb were to be used for a few hours per day, an investment of $5000 would be required. At simple depreciation over 20 years, it would cost the owner $250 annually to operate one light bulb. Obviously, the solar cell needs to become cost-effective through research and manufacturing development. Progress is being made in the direct conversion of the sun to electricity, but it is predicted that practical application of the photovoltaic cell is in the future.

In 1939, MIT I, a totally solar-heated home, was successfully constructed. A flat-plate solar panel covering more than half the roof collected solar energy and stored the energy in a 17,000-gallon water tank. The insulated tank held energy until it was needed. The present solar technology related to flat-plate collectors is in the advanced stage of development; however, the technology has existed for many years. Today, simple flat-plate collectors can be cost-effective. In other words, flat-plate collectors are competitive with fossil fuels. The flat-plate collector can provide energy for space heating and domestic or commercial water heating. This book is devoted primarily to the flat-plate solar heating system, which will be described later in detail.

It should be remembered that flat-plate collector design is primarily able to provide space and water heating. Space and water heating represents only approximately 20% of our energy needs. It would be unrealistic to expect much more than 10% of our energy demand to be supplied by flat-plate solar technology. The production of hydrogen for transportation and electrical power from the Rankine cycle using solar energy is under development.

Direct solar energy is radiant energy that is available every time the sun shines. This direct solar energy produces indirect solar energy, such as wind, waves, trees, and organic materials that can produce methane. Comparing direct solar with indirect solar, it can be seen that direct solar has the best chance of competing initially with fossil fuels. As an example, a typical home in the northern United States would require the following to provide total space heating:

1. a 1000-ft^2 solar flat-plate collector, or
2. an 87-ft-diameter wind generator, or
3. 1140 lb of chicken manure shoveled daily into a methane digestor, or
4. 200 lb of wood daily.

Clearly, wind generation and methane production have their place, but they cannot be considered feasible systems for space heating.

1.5 TREES AS ENERGY PLANTATIONS

The collection and storage of solar energy in trees planted for that purpose have good possibilities. Leaves collect and convert solar energy through the photosynthesis process. Fast-growing hybrid trees could collect and store enormous amounts of solar energy. Nonproductive farmland or other non-agricultural lands could be converted to energy plantations. The trees could be planted near cities and fertilized with sewage. Wildlife and recreational areas would be a by-product of energy plantations.

Mechanized processing and fuel preparation could produce a fuel compatible with our present life-style. The processed wood could be used to produce electricity or to power steam-driven vehicles that would pull into a wood station for a "fill-up" with processed wood chips.

In the state of Michigan, there are produced annually 200,000,000 tons of waste wood. If this waste wood, which consists of bark, limbs, sawdust, and depreciated lumber, were reprocessed and used as fuel, all the state's energy needs could be met. If waste wood has such a potential in Michigan, energy plantations certainly hold great potential for a renewable energy source.

From the flat-plate-collector design point of view, trees have helped advance solar technology. Collecting surfaces painted leaf green absorb solar energy about as well as do black surfaces.

1.6 SOLAR COLLECTORS

There are two basic types of solar collectors: the concentrating solar collector and the flat-plate collector. The *concentrating collector* uses a curved surface, usually a parabolic shape, to concentrate the sun's rays at a center or focal point. At the focal point, a black pipe filled with water or other liquid is heated. In this way, hot water, or even steam, can be generated. The concentrating collector produces what is called high-grade energy; that is, the liquid can be heated to high temperatures of 200 to 300°F. The main advantage of the concentrating collector is its ability to generate high-grade temperatures. The main drawbacks are twofold: (1) it is expensive to make, and (2) it must follow the sun in order to work if the collecter is a parabola or a truncated cone type. The second drawback requires expensive mechanisms and, therefore, contributes to the cost. Fixed non-tracking concentrators are available that are technically and economically between the flat-plate and tracking concentrator.

The *flat-plate collector* is made up of an enclosed box or panel in which an absorber plate is located. The panel is then covered with either plastic or glass. The main advantages of the flat-plate collector are: (1) it can be

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