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ABSTRACT

Student materials are presented for the course, Non-Residential Applications and Future Technology, one of seven core courses in Navarro College's two-year associate degree program for solar technicians. First, introductory material discusses the form and objectives of the course and ways of using the student materials. Next, readings, worksheets, bibliographies, and illustrations are provided for each of the six components of the course: (1) architectural, commercial, and industrial power demands, which includes units on the history of energy use and thermal energy classification by temperature range; (2) the agricultural application of solar technology for livestock shelters, crop drying, greenhouses, distillation, and irrigation; (3) commercial applications of solar technology; (4) industrial applications; (5) photovoltaic power systems, which includes units on the elements, technology, applications, and economics of photovoltaics; its social aspects; and options for improvement; and (6) the future applications of solar technology in cooling systems, solar central power stations, ocean thermal energy conservation, biomass conversion, and harnessing wind power. (HB)

SOLAR ENERGY

NAVARRO COLLEGE
CORSICANA, TEXAS

NON-RESIDENTIAL APPLICATIONS AND FUTURE TECHNOLOGY

Student Material

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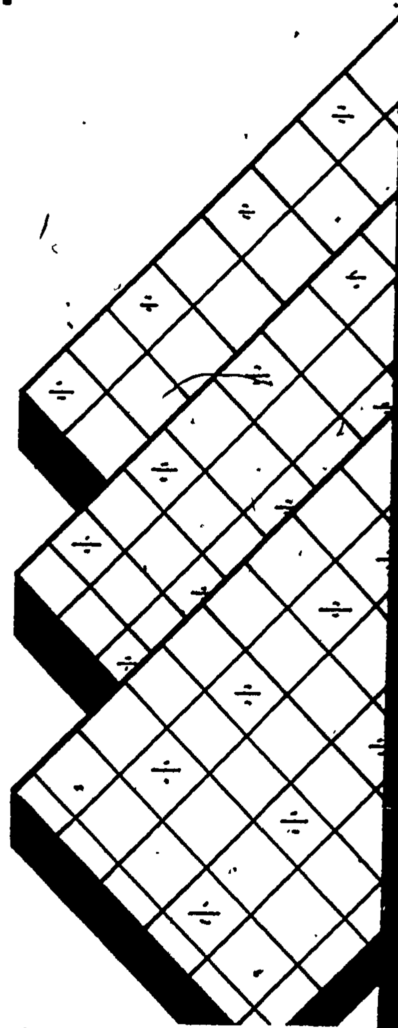

NAVARRO COLLEGE
CORSICANA, TEXAS

Student Material

NON-RESIDENTIAL APPLICATIONS AND FUTURE TECHNOLOGY

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NON-RESIDENTIAL APPLICATIONS AND FUTURE TECHNOLOGY

Student Material

CONTENTS

NON-RESIDENTIAL APPLICATIONS AND RUTURE TECHNOLOGY

PREFACE

The United States is facing one of its most challenging decades in recent history. Fuel supply and inflationary prices have forced us to consider alternate energy sources as a means of preserving our standard of living, industrial society, and economic stability. One such alternative is solar.

Presently, foreign crude oil provides the raw material for about one-half the liquid fuel production in the U.S. Political instability in foreign oil-producing countries underscores the need to decrease our ever-growing dependency on foreign energy sources and to lessen our vulnerability to such imports. Solar energy as an alternate can be used as a renewable domestic energy source and to supplement our increasing appetite for oil.

To help bring about the potential for solar energy, there must be a cadre of trained technicians to design, install, troubleshoot, and market solar energy so that the consumer can feel comfortable in the market's ability to service and react to his/her solar energy needs.

With the support of the National Science Foundation, Navarro College, in consortium with North Lake College, Brevard Community College, Cerro Coso Community College, and Malaspina College, has developed and pilot tested a two-year associate degree curriculum to train solar technicians. It can be duplicated or replicated by other educational institutions for their training needs.

The two-year technician program prepares a person to:

1) apply knowledge to science and mathematics extensively and render direct technical assistance to scientists and engineers engaged in solar energy research and experimentation;

2) design, plan, supervise, and assist in installation of both simple and complex solar systems and solar control devices;

3) supervise, or execute, the operation, maintenance and repair of simple and complex solar systems and solar control systems;

4) design, plan, and estimate costs as a field representative or salesperson for a manufacturer or distributor of solar equipment;

5) prepare or interpret drawings and sketches and write specifications or procedures for work related to solar systems; and

6) work with and communicate with both the public and other employees regarding the entire field of solar energy.

This curriculum consists of nine volumes:

1) an Instructor's Guide for the eleven solar courses, to include references, educational objectives, transparency masters, pre-tests and post-tests, and representative student labs;

2) an Implementation Guide addressing equipment, commitment, and elements to be considered before setting up a solar program;

3) Student Material for each of seven of the core solar courses:

   a) Materials, Materials Handling, and Fabrication Processes;
   b) Sizing, Design, and Retrofit;
   c) Collectors and Energy Storage;
   d) Non-Residential Applications;
   e) Energy Conservation and Passive Design;
   f) Codes, Legalities, Consumerism, and Economics;
   g) Operational Diagnosis.

ACKNOWLEDGMENTS

Throughout this project, many people and institutions have contributed greatly to the development, pilot test, and completion of the solar technology curriculum. First, this project owes a debt of gratitude to the National Science Foundation whose support and encouragement have made this project possible. Specifically, two individuals formerly with the National Science Foundation deserve recognition: Dr. Bill Aldridge and Dr. Gregg Edwards.

Appreciation is extended to thos members who served on the Advisory Committee and provided valuable input to module content, text format, and the pilot test plan and evaluation:

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USE OF THE STUDENT MATERIALS

The intent of this manual is for student use as a supplement to the instructor's guide for the same course. It contains readings, exercises, worksheets, bibliographies, and illustratons to reinforce the concepts contained within this particular course of study. Each student materials manual is written in a similar format but differs in some details due to the nature of the course and the subject matter covered.

Pretests, posttests, and lab exercise are not contained in this manual. Refer to the instructor's guide for this course to find these items.

Student materials manuals are supplied for seven of the eleven solar courses in this project. The four not included are: Introduction to Solar Energy, Energy Science I, Energy Science II, and the Practicum.

The pagination code is used as follows:

I -- the Roman numeral coordinates with the Roman numeral of the instructor's guide.

S -- the "S" signifies that the page is from the Student Material.

5 -- the Arabic number reflects the specific page within this manual, numbered sequentially throughout.

NON-RESIDENTIAL APPLICATIONS AND FUTURE TECHNOLOGY

NOTES TO THE STUDENT

The Student Material contained in this course is made up of a selection of readings from three basic books. It is not necessary for the student to purchase each of these books, although they would be excellent references for any solar student. It is necessary, however, that the students have access to each of these books in order to get full benefit from this course, the readings, and the discussions.

The three books are:

Kreider, Dr. Jan F., and Dr. Frank Dreith, Solar Energy Handbook, McGraw-Hill, 1981.

Dixon, A.E., and J.D. Leslie, Solar Energy Conversion, Pergamon Press, 1979.

Maycock, Paul D., and Edward N. Stirewalt, Photovoltaics: Sunlight to Electricity in One Step, Brick House Publishing Co., Andover, MA, 1981.

NON-RESIDENTIAL APPLICATIONS AND FUTURE TECHNOLOGY

ARCHITECTURAL, COMMERCIAL, AND INDUSTRIAL POWER DEMANDS

STUDENT MATERIAL

NON-RESIDENTIAL APPLICATIONS AND FUTURE TECHNOLOGY

Architectural, Commercial, and Industrial Power Demands

UNIT 1. Brief History of Energy Use

READING: Chapter 1, "History of Applications," of Meinel, Aden B., and Marjorie P. Meinel, Applied Solar Energy: An Introduction, Addison Wesley, 1976.

This selection will give the students an overview and an understanding of the history of solar applications throughout the world. It is well written and is accepted in the solar field as an excellent representation of solar historical perspective. The source is commonly available in a well-stocked library.

NON-RESIDENTIAL APPLICATIONS AND FUTURE TECHNOLOGY

Architectural, Commercial, and Industrial Power Demands

UNIT 2. Thermal Energy Classification by Temperature Range

READING: Chapter 4 of: Daniels, Farrington, Direct Use of the Sun's Energy, Ballantine, 1964.

Chapter 7 of: Kreider and Kreith, Solar Energy Handbook, McGraw-Hill, 1981.

In the past ten years the public has become increasingly concerned with the rapid depletion of and the escalating cost of both synthetic and fossil fuels. Likewise, the general public has shown concern about the possible environmental and safety risks associated with fossil fuels and nuclear power. Because of these concerns, world-wide attention has been focused on the potential of harnessing the sun's power to meet society's growing energy needs.

Optimistic proponents of solar energy predict by the year 2000, as much as 20% of the United State's energy needs could be supplied by solar power. The attainment of this goal will depend upon the combined effort of both solar industry and those advocates found in education who by working together will develop informed, knowledgeable, and competent practitioners.

In the area of non-residential solar applications, the solar energy industry and their research counterparts have placed great emphasis on the development of active solar energy systems which involve the integration of several subsystems: solar energy collectors, heat exchangers, heat storage containers, fluid transport and distribution systems, and control systems. The major component unique to active systems is the solar collector.

In this unit we are going to concentrate on that solar collector to evaluate and make a decision on which collector to select for a specific non-residential application. The student must understand the process for comparing performance curves of those specific collectors. Even though the performance curve is an ideal tool for comparing similar types of flat plate collectors, it cannot be used to compare flate plate to concentrator collectors because of the design criteria that were used in the evaluation and development of those performance curves. A quality comparative evaluation also requires that the entire system be part of the evaluation in that similar collectors utilize the same components when it comes to system evaluation and, while collector and system performance is the important parameter in the design, it is not necessarily the deciding parameter since, in most cases, the most efficient collector also is the most costly. So, during the design process the final evaluation must also include a payback analysis of the investment.

Most manufacturers of solar collectors and solar systems provide data on the efficiencies of their equipment. Some of this information is derived from measurements made by that manufacturer. As the federal government and local governments become involved in the construction and insolation process of solar systems, we are finding out that the requirement for an independent testing evaluation of systems is proving to be very profitable. By developing specific testing procedures that depend on specific test conditions and evaluating each collector in each system under those same conditions, we are given a meaningful data source for the designer to use as a comparative tool.

Various standards for solar collector performance testing and for design and installation of solar equipment either already exist or are being drafted in several countries. Working groups of the International

Energy agency (IEA) also are considering the problem. A single international standard would seem desirable so that the designer could compare solar equipment manufactured throughout the world. In the United States itself, a proposed but not solely adopted by all states, standard for collector performance testing was published by the National Bureau of Standards (NBS). A modified version of that performance testing standard was adopted by the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE). This standard covers both liquid and air collectors with specifications for outdoor testing and for indoor testing with the solar similator.

In order to determine the efficiency of a solar collector, the rate of heat transfer to the working fluid must be calculated. The rate of heat transfer to the fluid flowing through a collector depends on only the temperature of the collector surface from which the heat is transferred by convection to the fluid, the temperature of the fluid and the heat transfer coefficient between the collector and the fluid, as already has been mentioned. The results of thermal performance test for solar energy collectors are generally presented by plotting the efficiency as a function of the difference in temperature between the inlet to the collector and the ambiance divided by the solar flux incident on that collector.

In order for the student to have a firm grasp of these concepts and to be able to progress through the remainder of this course, please refer to Kreider and Kreith, The Solar Energy Handbook, Chapter 7, "Non-Concentrating Solar Thermal Collectors". This knowledge will be needed as the various types and forms of non-residential solar applications and future technologies are discussed.

NON-RESIDENTIAL APPLICATIONS AND FUTURE TECHNOLOGY

AGRICULTURAL APPLICATIONS

S T U D E N T   M A T E R I A L

NON-RESIDENTIAL APPLICATIONS AND FUTURE TECHNOLOGY

Agricultural Applications

OVERVIEW

For centuries farmers have dried their crops in the sun, and their greenhouses have been partially heated by solar heat. Recently, agriculture, because of the rising cost in fossil fuels, has been developing new applications for the use of solar energy in the areas of animal shelters, crop drying and curing, pumping of water, and biomass conversion.

The temperature level of operations for agricultural processes varies, depending on the type of crop or the process being used. In the concept of animal shleters, room temperature, which could be easily developed by passive solar sources, depends upon the type of livestock being housed. When it comes to food processing and drying, there are indeed some very specific levels but all attainable by the application of solar energy. These could be sun-drying (temperatures up to 50°C); solar drying (temperatures up to 100°C); poultry and livestock food processing (temperatures between 50° and 80°C); produce sterilization in canning (temperatures of 110°C to 120°C); cotton processing (temperatures of 100°C to 180°C); and even milk pasteurization (temperatures of 63°C to 72°C). Therefore, agriculture applications can indeed utilize solar energy as a source of thermal energy.

NON-RESIDENTIAL APPLICATIONS AND FUTURE TECHNOLOGY

Agricultural Applications

UNIT 1. Livestock Shelters

The most economic approach to heating and even cooling of livestock shelters is to do it as simply as possible using existing materials and technology and letting nature do most of the work. Past civilizations involved various forms of architecture that used natural conditioning effects of the sun, wind, and water to keep environmental spaces comfortable. Different climates have produced traditional architectural and construction styles that are tailored to local conditions. Compact masses for hot aired regions with cold, harsh winters, and double roofs in the desert areas where abundant sunshine exists, plus wind for convective cooling have proven productive.

The direct solar approach has major advantages including simplicity, low cost, reliability, and durability. The ideally shaped structure would gain a **maximum** amount of solar energy in the winter and lose a minimum amount of heat. Then during the summer it would do the opposite. Computer simulated studies indicate that for a structure located at 40° north on a flat, open, unshaded site, the minimum solar heat gain in the summer will be for a rectagular structure with a long dimension ranging from one to one and one-half times the short dimension and with a longer axis in the east-west direction. That structure, with proper orientation and sheltering and shading, can be an ideal livestock shelter.

In planning the shelter, choosing the location and deciding on the type of structure are the two major decisions to be made during the planning phase. The choice of location will be affected by the orientation, shading, wind shelter, and need for drainage or leveling, and the accessibility of various other sites, local pasture, exercise areas, and acceptability to transportation in and out. The choice of type will be affected by what you can afford, whether you intend to buy a prefabricated model or build one youself, and, of course, the temperature and environmental requirements of the livestock to be sheltered in that structure.

STUDENT EXERCISE:

1. In the Instructor's Guide, there are some laboratory exercises designed to help the student understand the design and function of lovestock shelters and the potential for solar use with them. Students should be given these laboratory exercises at this time.

2. Take a field trip to a farm or ranch and observe the heating requirements of the livestock shelters. Discuss and/or design a solar application to assist with this heating activity.

3. Make a report on livestock shelter requirements in your area. Identify the heating and/or cooling activities associated with them. Consider the possibility of adding solar to offset these requirements.

NON-RESIDENTIAL APPLICATIONS AND FUTURE TECHNOLOGY

Agricultural Applications

UNIT 2. Crop Drying

The utilization of solar energy in the crop drying process can be sub-divided into two general categories: first, the drying of grains; and second, the drying of high moisture crops. Grains have a low moisture content, around 20% to 30% at time of harvest. For them, the drying process lowers that moisture content to a 12% to 14% level for ideal storage without biological degradation. Moist crops, like fruit, require the drawing of high moisture contents, normally above 50%. The moisture level for the moist crop depends upon the end use of that crop. If the crop is to be sold for human consumption, the moisture content during drying is at a moderate level, depending upon the crop. If the same crop is to be used as a feed product for animal production, then the moisture content is much less.

The modern day role of solar energy in crop drying has not changed since the earliest farmers. Moisture is removed from the crop by warmed air across the surface of that crop. Solar energy is used to increase the temperature of that warmed air stream and in some cases produce the movement in the stream through a form of solar siphoning. The single major problem with crop drying is that either heat must be maintained at a specific low temperature or at a very high temperature. Any fluctuation in between those two temperatures accelerates spoilage. Therefore, in considering the design of a crop dryer, the student must understand the crop to be dried, the ideal temperature of equilibrium vapor pressure, and its spoilage temperatures, to make a qualified evaluation of a design.

READ: Dixon, A.J. and J.D. Leslie, Agricultural and Other Low-Temperature Applications of Solar Energy, Pergamon Press, 1979.

SUMMARY OF: Chapter 18:

One of the oldest uses of solar energy since the dawn of civilization has been the drying and preservation of agricultural surpluses. The methods used are simple and often crude but reasonally effective. Basically crops are spread on the ground or platforms often with no pre-treatment and are turned regularly until sufficiently dried so that they can be stored for later consumption. Little capital is required of equipment but the process is labor-intensive.

There are several technical problems, however, with this basic drying process. They are:

-- cloudiness
-- insect infestation
-- high levels of dust and atmospheric pollution
-- intrusion from animals and man.

The chapter continues by discussing the technical characteristics of solar agricultural dryers and then the solar dryer classifications:

-- passive systems
-- sun or natural dryers
-- solar dryers--direct
-- solar dryers--indirect
-- solar lumber dryers
-- chamber dryers
-- rack or tray dryers
-- hybrid systems.

The chapter continues by describing several types of solar dryers:

-- drying of grapes on racks
-- solar cabinet dryer
-- see-saw dryer
-- glass roof solar dryer
-- solar fruit and vegetable dryer
-- solar wind ventilated dryer
-- solar supplemental heat drying bin (Semiindustrial type)
-- large-scale solar agricultural dryer (Barbados)
-- solar timber seasoning kiln.

NON-RESIDENTIAL APPLICATIONS AND FUTURE TECHNOLOGY.

Agricultural Applications

UNIT 3. Greenhouses

As early as the fifth century B.C., records show the Greeks were describing the gardens of Adonis, usual locations where exotic plants flourished. Plato once wrote, "A grain of seed or a branch of a tree placed in these gardens acquires in eight days the development which can only be obtained in as many months in the open." Even though we have no graphic record that these gardens were not in the open air, we cannot tell whether they were actually enclosed greenhouses or merely sheltered gardens. The first written record of the greenhouse per se was during the first century A.D. where we find the Romans were growing fruits and vegetables in very simple greenhouses which we now call coldframes. The Romans generally used thin sheets of talc or mica to cover their coldframes. It is recorded that Caesar was ordered by his doctor to eat cucumbers and, assigning his gardener the chore, his gardener managed to produce cucumbers every day of the year, using a large coldframe and the cucumbers in a biomass mixture of soil and decomposing manure. These coldframes were moved inside at night to be kept warm during the evening hours.

From that first century A.D. date, to the late 16th and 17th centuries during the Middle Ages, greenhouses appear to have been virtually unknown. During the 16th century, European traders and explorers began to bring back exotic plants that could not survive in the typical European climate. For the botanist to look after these rare and delicate specimens, a special type of botanical garden was developed, first in Italy and then in Holland and England. John Evelyn, a 17th century British diarist who wrote botanioal tracts was supposed to have coined the word "greenhouse" and invented one of the first hot air heating systems to be installed in the greenhouse. Then during the late 17th century on into the 18th century, we began to develop concepts that dealt with prime factor angles for healthy growing plants. Sloped glass was introduced into the greenhouse structure by the Dutch. The 19th century brought new inventions and improvements: the technology of building and managing greenhouses.

By the turn of the 20th century, the large geenhouse conservatory was growing out of fashion. Domestic greenhouses began to dwindle but the commercial applications of greenhousing began to expand. Commercial greenhouses covered acres of land, producing tons of tomatoes and cucumbers and lettuce for the winter marketplace. This commercial application pushed greenhouse technology in new directions. Ideal heating, humidifying, watering, and fertilizing all developed new innovative teohniques. Then, in the early 70's, the increasing cost of fuel encouraged work on less energy consuming greenhouses. The history then of greenhouses seems to have completed a full cirole. Most domestic greenhouses today are fairly small, simple structures, designed to capture the sun's warmth so that fruits and vegetables and flowers can be grown out of season. In designing a commercial application greenhouse, the choosing of the location and the type of building are the two major decisions to be made in the initial planning. The choice of location will be affected by the orientation, the shading, the wind shelter, the need for drainage or leveling, and the accessibility of various sites that are local to the greenhouse for storage, for movement of produce in and out. The choice type will also be affected by the expense, whether it is intended to buy a prefabricated model to build a structure from scratch. And, of course, the requirements of the plants that will be grown in the structure.

The main aim in sighting a greenhouse for general use is to maximize the light, particularly during the winter months. The building must be able to temper the extremes of climate and maintain suitable conditions for plants without relying upon too much non-renewable energy. Southwest facing greenhouses receive maximum exposure to direct sunshine at the time of day when the outside air temperature is also the hottest. This mid-afternoon time period, when the sun is low with maximum intensity it usually when the greenhouse is already to an operational temperature, thus, increasing the temperature within the greenhouse. On the other hand, a southeast exposure is more beneficial because the plants get the boost of the early morning sunlight and the warmth early in the day when the air temperature in their environment is normally lower.

Whatever the orientation of the greenhouse a general conclusion is that most greenhouses overheat during the summer months unless they are partially shaded. Greenhouse shading can either be architecturally through the use of shades, shudders, insulation systems, and even overhangs, or can be natural by the use of trees. Deciduous trees which conveniently lose their leaves during the winter, tend to be the best shading trees for use around the greenhouse. Those trees can also provide useful wind breaks which reduce the heat loss from the greenhouse during the winter and in turn decrease the energy consumption from non-renewable energy sources. The average heat loss through glass increases by as much as 50% when wind blows across it. This is because a major factor in the rate of heat loss is the speed of the air moving across the surface of the glass. It would thus be advantageous in choosing a site for a greenhouse that is not only exposed to adequate sunlight but also could be sheltered from the winds by either natural wind barriers or by trees and hedges. The tree or the hedge form the best kind of wind break since they absorb the force of the wind within their branches, where fixed or solid breaks such as fences or natural bluffs tend merely to deflect the wind causing it to gust and sometimes to increase in force.

A complete souce of greenhouse information would be <u>The Complete Greenhouse Book</u> by Peter Clegg and Derry Watkins. It is a Gardenway paperback and covers both the history of greenhousing and the applications of the current 20th century greenhouses. It would be a very good resource book to utilize for you laboratory experiments.

READ: Sayigh, A.A.M, "Greenhouses in Hot Climate", College of Engineering, University of Riyadh, Riyadh, Saudi Arabia, in Solar Energy Conversion, by A.E. Dixon and J.D. Leslie, Pergamon Press, 1979, Chapter 43.

SUMMARY OF: "Greenhouses in Hot Climates".

Various systems based on environmental control are discussed. The use of shelter--natural or artificial, selective shelter and special greenhouses are discussed in relation to a variety of climatic conditions. The use of passive cooling coupled with the Ruthner principle are studied, particularly with regard to their future role in agricultural continuous production. Some examples of existing greenhouses in the neighborhood of Riyadh are discussed. Several unusual designs of greenhouses, such as those developed by Brace Research Institute and Polysolar Company, are fully discussed. In the concluding remarks, several recommendations are mentioned and all systems are compared with each other.

READ: Brundrett, E., "Solar Greenhouse Design Considerations for Cold Climates", Department of Mechanical Engineering, University of Waterloo, Waterloo, Ontario, Canada, in Solar Energy Conversion by A.E. Dixon and J.D. Leslie, Pergamon Press, 1979.

SUMMARY OF: "Solar Greenhouse Design Considerations for Cold Climates"

The writer's attention was returned to the need for solar energy design in Ontario greenhouses by the energy crisis of 1973-74, and the subsequent rapid increase of fossil fuel costs for traditional greenhouse heating systems. In Ontario the cost of fuel for tomato crops has increased from 10% of annual operating costs to a current level of 40%, for traditional cultivation practice. Many efforts have been made to reduce the dependancy upon fossil fuels while retaining a viable greenhouse industry, including shut down during the coldest winter months, reduced growing temperatures, and reduction of heat loss by good maintenance and in some instances the application of light weight insulation curtains. However not all of these measures have been cost effective. Often reduced temperatures have lead to crop reductions far in excess of the fuel savings, while winter shut down tends to place Ontario vegetable greenhouse operators in the same market period as field crops grown in Florida, Mexico and California.

Even with the measures adopted to date the energy problem remains critical for tradtional vegetable greenhouse operators. It is well to recognize that the current practice requires 48 - 96 l/m^2-yr, (1-2 Imp Gallons/ft^2-yr), of fuel, based upon growing temperatures of 16°C (62°F), current single pane glasshouse construction, and current heating plant efficiencies. It is also necessary to recognize that the current vegetable greenhouse industry in Ontario uses up to ten times the fuel per

Kilogram of tomato produced, as that required to field grow and truck a comparable weight of tomatoes from Mexico or California. The ratio is more unfavorable when the comparison is made with Florida field grown tomatoes.

Thus it is more than evident that the high energy demands of the Ontario vegetable greenhouse industry must be solved. In a recent greenhouse energy study by the author and colleagues for the Ontario Ministry of Agriculture and Food, and the Ontario Ministry of Energy it was noted that the energy solution must be found in three general areas. First in view of the cold winter climate of all of Ontario it is necessary to explore means of providing effective nightime insulation. Second it is necessary to increase and then to maintain a higher thermal efficiency for the whole greenhouse operation, including thermal plant efficiency, heating pipe insulation, and waste heat recovery, including that found in ventilation air. Third it is desirable, where economically and structurally practical to incorporate passive and active solar storage systems within current greenhouses. Finally solar storage systems are recommended for new greenhouses.

NON-RESIDENTIAL APPLICATIONS AND FUTURE TECHNOLOGY

Agricultural Applications

UNIT 4. Distillation

The solar distillation process, like many forms of solar energy collection, is not new to the 20th century. In 1551, we see the Arabic nations utilizing stills for the production of drinking water. In 1589, we begin to see the first historical desalination of salt water. From there the same activities of distillation were used in the distillation of herbs. In 1742, an Italian published the first specific reference for the use of solar in the distillation of salt water. Then, as in the progression of the history of many other solar devices, not until the late 1800's, 1900's, and into the 20th century do we see the application of the soalr distillation of water coming into prominent use. In the early 1900's in Las Salinas, Chile, a green-roof type solar still was produced in order to supply fresh water for growing of crops and for the community. In the early 1900's very few reports of solar stills were published. In the decade following World War I, increased interest was renewed in the process of solar distillation.

The simplest type of distillation system is considered the single-effect system. In the single-effect system, the heat of vaporization is not recovered and therefore maximum energy is being consumed for the vaporization of water. In a multiple-effect system, some of the heat of vaporization is recovered, requiring less energy per gram of water produced. The distillation of water does not imply boiling in the clinical sense. The process that occurs is, in the presence of a cold surface water, evaporated from the surface of a warm water source and condenses on that cold surface. The simplest water distillation system therefore, consists of a shallow pool of water in some sort of enclosure, having a transparent cover. This transparent cover, being exposed to the environment, will be cooler than the air inside of this enclosure, The water will be even warmer than the enclosed air. The vapor pressure of water will tend to saturate the air within this enclosure at equilibrium to the water temperature. The transparent cover will tend to limit the saturation of air to be appropriate or equal to the temperature of that surface. The result is the net transfer of water from the hot water to the cool window, in turn, a full distillation process.

As we see the demand on potable water increasing in large populace areas, we see the increased possibility of solar desalination processes becoming more and more reality.

The major component parts of the solar still are: transparent cover, the evaporator liner, the solar still frame, sealants, insulation, and the auxiliaries, such as piping, plumbing, and reservoirs. The overall specifications of a solar still contain a few basic requirements that can be considered to be common. The first one is: the still must be easily assembled in the field. The second criteria should be that the still be constructed to materials imported to the region that are packagable so that transportation costs will not be excessive. The design characteristics should provide for a light-weight design for the ease of handling in shipping. The design process should have considered that the effect of life with minimum normal maintenance should be ten to twenty years to be a cost effective still. Because of the configuration, the still must have access ports for the ease of maintenance. The still should not require or depend upon any form of external power sources. The ideal design would insure that the still would serve as a rainfall catchment surface along with being a solar still. The design should also be able to withstand the effects of severe storms, both wind, rain, and hale. Last, as a general specification, the still must be manufactured of materials which will not contaminate the collected rain water or distillant. During the design process, it must be continuously stressed that the solar still constitutes the water supply system for the community served and hence must be non-toxic in every respect to the fresh water produced.

The first component of the solar still would be the transparent cover. This cover serves to cover the distillation segment and transmit solar radiation to the interior. The next components would be the evaporator liner. The evaporator or basin liner serves as the absorbing surface of solar radiation as well as a container for the saline water. The materials used for this purpose whould have the following properties or characteristics: it must be impervious to water, must have solar absorptions along the lines of a .95, should be fairly smooth to discourage the depositing of scale, should not deteriorate or decompose on contact with normal soils, the materils must withstand the effect of continuous emersion in hot saline water, and the last being the basin liner should not emit any gases or vapors which would taint the taste of the fresh water distillant.

The solar still frame is the third solar still component. The frame refers to the materials which are used to form the frames of the evaporators. Any materials used in this fashion should be resistant to attack from the saline water or atmosphere.

The next components are sealants. These are the materials used to seal transparent cover materials to one another as well as to other components of the the distillers. It also includes any members used to support the super structure of the distillation units as they will have invariably come in contact with the transparent cover. Following in the list components is insulation. The insulation used in the solar distillation is used beneath the seawater evaporator basins in order to reduce ground heat loss. The materials used for this purpose require the follwing properties: they must be light weight and structurally self-supporting, waterproof and basically water impermeable, should insulate the edges as well as the base of the evaporator, and withsatnd temperatures up to 80°C.

The last component would be the auxiliaries, piping, pumping, and reservoirs. These auxiliaries include all fluid systems: gutters for rainfall, condensates, collection, piping for feed and rainlines, and reservoirs for the saline and fresh water.

Additionally, information and other agricultural and low temperature applications can be found in <u>The Solar Energy Handbook</u> by Kreider and Kreith, Chapter 18, "Agricultural and Other Low Temperature Applications of Solar Energy". Along with solar distillation, evauation systems, sizing systems, and processes for estimating system, they also expand upon solar cooking in the same chapter.

READ: Lawand, T.A., "Agricultural and Other Low-Temperature Applications of Solar Energy", Brace Research Institute, Montreal, Quebec, in Solar Energy Handbook by Kreider and Kreith, McGraw-Hill, 1981, Chapter 18.

SUMMARY OF: "Agricultural and Other Low-Temperature Applications of Solar Energy"

Intermediate-technology solar systems use simple fabrications methods, can be built on site from nonfabricated components, usually have low unit cost, and operate at temperatures below 100°C. As such they find wide application in the developing world or by the do-it-yourself worker. Since the devices are of simple design, no detailed engineering analysis is required. The basic principles of heat transfer and solar radiation can be used to estimate performance.

This chapter discusses three intermediate-technology systems--solar distillation, solar cooking, and solar crop drying. Basic design guidelines and illustrations are provided but detailed theories are not developed. A lengthy bibliography is given for additional study.

NON-RESIDENTIAL APPLICATIONS AND FUTURE TECHNOLOGY

Agricultural Applications

UNIT 5. Irrigation

READ: Bahadori, M.N., "Solar Water Pumping", Department of Mechanical Engineering, Pahlavi University, Shiraz, Iran, in Solar Energy Conversion by A.E. Dixon and J.D. Leslie, Pergamon Press, 1979, Chapter 45.

SUMMARY OF: "Solar Water Pumping"

The principles of solar water pumping are briefly described. The mechanical energy needs for pumping water may be produced by thermodynamic--or direct-conversion methods. In thermodynamic conversion a fluid with high internal energy is produced in solar collectors or concentrators. The internal energy of the fluid may be utilized in Rankine-, Brayton-, or Stirling-cycles or in specially designed devices. The nature of irrigation in the arid regions calls for scattered water pumping stations, hence small solar pumps. These pumps may be mass produced and delivered to the site.

The direct conversion includes photovoltaic, thermoelectirc and thermionic processes. With the current prices of solar cells photovoltaic water pumping seems to be economically competitive with the current solar Rankine-cycle system in the power ranges of below 5 KW, especially when both systems have to be imported by a developing country.

FURTHER READINGS

1. Bahadori, M.N., "Energy Sources and Uses in Iran--A Brief Review", International Institue for Applied Systems Analysis, Laxenburg, Austria, Report No. WP-76-25, 1976.

2. Tabor, H., "Solar Ponds--Large Area Solar Collectors for Power Production", Solar Energy Journal, Vol. 7, No. 4, 1963, pp. 189-194.

3. Weinberger, H., "The Physics of the Solar Pond", Solar Energy Journal, Vol. 8, No. 2, 1964, pp. 45-55.

4. Anwar, M.M., "Development of a Solar Powered Equipment for Operating a Small Irrigation Pump", Final Technical Report, 1967 Pakistan Atomic Energy Organization, Lahore.

5. Duffie, J.A., and W.A. Beckman, Solar Energy Thermal Processes, John Wiley and Sons, New York, 1974.

6. Tabor, H., "Mirror Boosters for Solar Collectors", Solar Energy Journal, Vol. 10, No. 3, 1966, pp. 111-118.

7. Winston, R., and H. Hinterberger, "Principles of Cylindrical Concentrators for Solar Energy", Solar Energy Journal, Vol. 17, No. 4, 1975, pp. 255-258.

NON-RESIDENTIAL APPLICATIONS AND FUTURE TECHNOLOGY

COMMERCIAL APPLICATIONS

S T U D E N T   M A T E R I A L

NON-RESIDENTIAL APPLICATIONS AND FUTURE TECHNOLOGY

Commercial Applications

UNIT 1. General Applications

Commercial solar thermal enrgy applications are based upon their use, such as hot water, steam, space heating and space cooling. To properly analyze the needs of the commercial applications, some form of analysis must be completed. A variety of analysis methods exist for the design and study of solar heating and cooling systems. These methods range from computer simulation to programs for hand-held calculators. The following brief description of the more common methods now in use were derived from a recent publication from the Solar Energy Research Institute.

1. BLAST (building load analysis system, thermal dynamics) -- similar to DOE-1, BLAST is a heating and cooling loads calculation program which performs hour by hour thermal balances and has a capability of simulating solar systems. It is intended for the use in the heating, ventilating, and air conditioning industry. Contact: Doug Hittle, U.S. Army Construction Engineering, Research Laboratory, P.O. Box 4005, Champaign, IL 61820.

2. DEROB (dynamic energy responses of buildings) -- DEROB is an hourly load simulation program which was developed by the architectural department at the University of Texas and is aimed at passively heating homes. The program presently is being tested throughout simulation runs. Contact: Francisco Arumi or David Northrup, University of Texas at Austin, Department of Architecture, Austin, TX 78712.

3. DOE-1 (Formerly known as the CAL-ERDA) -- DOE-1 has been a joint development effort of the Lawrence Burkley Laboratory, Los Alamos

Scientific Laboratory, and Arigonne National Laboratory. The program has been funded by the Department of Energy. DOI-1 provides HVAC load analysis compatibility as well as total energy system analysis compatibility. It is intended to be used primarily by HVAC engineers and architects. Contact: Fredrick Winkelmann, Lawrence Burkley Laboratory, One Cyclatron Road, Burkley, California 94720.

4. F-Chart -- The f-chart is a simplified solar system design technique developed by the University of Wisconsin Solar Laboratory. F-chart is an interactive program to which the users supply simple answers to 46 building questions. Weather data also are built in. All f-chart versions are based on the TRNSYS program. F-chart version 3 is available through SERI at the cost of $100.00 for the tape or $150.00 for the cards. Contact: F-chart, Marketing Development Branch, Solar Energy Research Institute, 1536 Cole Blvd., Golden, CO 80401. A version for programmable calculators is available for $150.00. Contact: Sandy Klein, F-chart, P.O. Box 5562, Madison, WI 53705.

5. HISPER (High Speed Performance) -- HISPER is an hourly load simulation program used at the NASA Marshall Space Flight Center Solar Laboratory. It is similar to and has been compared with the TRNSYS program. The program is available but has limited documentation. Contact W.A. Brooksbank, Building 4201, Systems Development Office FA31. The National Aeronotics and Space Administration, George C. Marshall Space Flight Center, AL 35812.

6. HUD-RSVP (HUD Residential Solar Visibility Performance) -- The HUD-RSVP is a program to analyze thermal performance, economics, and financing of residential active solar systems. The thermal performance sector is based on the f-chart method and includes weather data for 172

accumulated cities. Contact: Dr. Frank Weinstein, National Solar Heating and Cooling Information Center, P.O. Box 1607, Rockville, MD 20350.

7. SKOTCH -- SKOTCH is a package of solar software programs for use in programmable calculators. It calculates through the f-chart method, the fraction of the heating load supplied by solar energy. Contact: Bob McClintock, SKOTCH Programs, P.O. Box 430734, Miami, FL 33104.

8. SEEC I-V (Solar Environmental Engineering Company I-V) -- SEEC I-V is a package of 5 programs for use in programmable calculators. It can provide heat load analysis, collector optimizing, heat exchanger sizing, and economic analysis. Contact: Solar Environmental Engineering Company, P.O. Box 1914, Ft. Collins, CO 80522.

9. SESOP -- SESOP is an hourly simulation program for solar space heating and cooling in process heat applications. Weather date must be supplied externally. Output includes detailed thermal analysis and life-cycle cost. Contact: Henry T. Crenshaw, Lockheed Space and Electronics, 1816 Space Park Drive, Houston, TX 77062.

10. SOLCOST -- SOLCOST, developed by Martin Marrietta Corporation, is a program based on the hourly simulation of an average day per month. It handles flat plate and tracking collectors as well as various thermal load modules. A version of the program has been limited to passive design capability. There is a service center set up to provide basic residential system sizing at a price of $35.00 or program may be obtained at a nominal cost. Contact: SOLCOST, International Business Services, Inc., Solar Group, 1010 Vermont Ave., N.W., Washington, D.C. 20005.

11. SOLOPT -- SOLOPT performs life-cycle economic and hourly

thermal analysis on solar space heating and domestic hot water systems. General weather data statistics are required as input for computer generation of an hour by hour weather data to perform the analysis. Contact: Dr. Larry O. Degelman, Department of Architecture, Texas A & M University, College Station, TX 77843.

12. SOLTES (Simulation of Large Thermal Energy Systems) -- SOLTES is an hourly simulation program developed by Sandia Laboratories with major emphasis on total power systems in process heat. The program also is capable of simulating active solar heating and cooling systems. Contact: SOLTES, M.E. Fewell, Division 1262, Sandia Laboratories, Albuquerque, NM 87115.

13. SYROL -- An hourly simulation program for solar space heating and cooling and domestic hot water specific to commercial buildings using unitary heat pumps. Provisions for the detailed heating load module have been incorporated. The program is available but has limited documentation. Contact: D. Manas Ucar, Mechanical Engineering Department, College of Engineering, Syracuse University, Syracuse, NY 13210.

14. TEANET (Total Encironmental Action Network) -- TEANET is a thermal network program for simulating passive building performance using a programmable calculator. TEANET calculates and prints the temperatures in each network mode on an hourly basis as well as the auxiliary energy consumption. The programs are designed to be used by architects and engineers. Contact: TEANET - Total Envitonmental Action, Inc., Churchill, Harrisville, NH 03450

15. TRNSYS -- The TRNSYS program is used for simulating the dynamic behavior of a variety of inner-connected components which form a solar HVAC system. The program solves the mathematical energy

balance equation for the component model to arrive at a detailed operation characteristic of the system. The program was developed by the University of Wisconsin Solar Energy Laboratory. Contact: Warren Buckles, University of Wisconsin, Solar Energy Laboratory, 1500 Johnson Drive, Madison, WI 53706.

The basic building block of any solar thermal energy system, commercial application, is the collector and therefore the most significant part of the design of the solar process heat system is concerned with the collector selection and sizing. Among the major variables affecting the choice of collector are: the required amount of process energy, the process energy demand pattern, required process temperatures, available solar energy, collector performance, and installed collector cost. The general procedure for evaluating various collectors and collector systems for specific applications would be to first conceptualize the solar system. To conceptualize the solar system, devise a flow schematic for the system similar to those shown in commercial applications and commercial advertisements. Evaluate collected data on the processes to which the solar thermal energy is to be applied, determine loads, load patterns, and minimum and maximum temperatures., Using solar radiation table, determine available solar radiation relevant ambiant temperatures for the location of the design system. Utilizing the commercial collector manufactured data or other approved methods, find the collector efficiency--that is the relationship between temperature end minus temperature ambient. With the collected data, develop a model which allows the system performance to be calculated. Evaluate this model to determine performance for different collector array sizes, configurations, and orientations. Using an approved economic optimizing procedure, determine the best system configuration. Repeat the aforementioned process for several alternative collectors, determining which has the greatest cost benefits or gives the greatest rate of return.

The procedure described is both costly and time-consuming but is normally carried out by the design engineer, the design engineering firms, or the solar designer for commercial projects.

READ: Fraser, M.D., and H.S. Liers, "Solar Process Heat Systems", InterTechnology/Solar Corporation, Warrenton, VA, in Solar Energy Handbook by Dr. Jan R. Kreider and Dr. Frank Kreith, McGraw-Hill, 1981, Chapter 21.

SUMMARY OF: "Solar Process Heat Systems"

The potential for the use of solar process heat in industry appears to be significant. Industrial process heat accounts for a significant fraction of the amount of energy consumed in the United States, and surveys have indicated that a certain portion of this process heat technologically could be provided by solar thermal energy.

The purpose of this article is to show how available solar technology can be utilized in an industrial environment. Part of the purpose of this article is to integrate the various elements of solar systems, such as collector types, storage, radiation, materials, and economics with information so that a system designer can carry out a preliminary assessment of how solar energy could be used for a particular process heat application. More specifically, the material presented in this article should enable him/her to select a system conceptual design, including collector type, and storage type and size to estimate the amount of energy provided by a solar process heat system and to perform a rough cost estimate. A method is also presented for calculating the optimal collector field size.

Finally, conceptualized solar process heat system designs are shown to illustrate some design principles and to point our some important considerations. Examples of systems are described--one experimental system and another example based upon the information in this article--to illustrate the possible design and use of solar process heat systems. Possible process applications are also suggested.

NON-RESIDENTIAL APPLICATIONS AND FUTURE TECHNOLOGY

INDUSTRIAL APPLICATIONS

S T U D E N T   M A T E R I A L S

NON-RESIDENTIAL APPLICATIONS AND FUTURE TECHNOLOGY

Industrial Applications

The future for the use of solar process heat in industry appears to be a realization. Today industrial process heat accounts for a specific fraction of the amount of energy consumed by the United States. Many surveys have indicated that a portion of the process heat technologically could be provided by solar thermal energy.

Among the various sectors of the United States economy, the largest energy user is the industrial sector. During the late 60's it accounted for 41% of the total national energy use, compared with about 19% of use within the residential sector, 15% use within the commercial sector, and 25% use within the transportation sector.

Again, in the late 60's, within the industrial sector the total industrial use of energy was about 2.64 times 10^{19} joules, or equivalent to about 25 times 10^{15} Btu's for all purposes. M.D. Frazier of the InnerTechnological/Solar Corporation suggests that the breakdown of total industrial use of energy should be as follows:

Processed Steam	40.6%
Electric Drive	19.2%
Electric Process	2.8%
Direct Process Heat	27.8%
Feed Stock (for chemicals)	8.8%
All Other Categories	.8%

Processed steam and direct process heat together account for about 68.4% of the total industrial use of energy. Through this industrial breakdown it is thus clear that the greater portion of energy used in the industrial sector is used in the form of thermal energy rather than the form of electric for power. The same breakdown also identifies the significant potential for the use of solar thermal energy in industry; however, one of the most important variables to consider in the application of solar thermal energy processes would be the terminal temperature that is required for that specific process.

During the early 70's, the temperature requirements for industrial process heat in the United States have been surveyd by two studies. In one of the two studies, the survey was performed from the point of view of the process requirement rather than the point of view of the current method of using the heat. Thus, the result of major interest was the required temperature of the process heat rather than the temperature at which the heat is currently being provided. The data collected from the study was presented in a form of cumulative process heat and showed the percent of industrial process heat that was used as a function of a thermal process temperature required.

The data base for the survey consisted of process heat data from 78 diverse industries as defined by standard industrial classification codes (SIC groups) in both mining and manufacturing industries. This data base included process heat applications consuming about 59% of the estimated total use of process heat by the United States industry during the mid-70's.

The results of this data developed some particular interest areas, the first being the percent of process heat needed at terminal process temperatures below the temperature of 100°C, about 7.5%. This demand could perhaps be provided by low temperature solar thermal energy systems. Twenty-six percent of process heat needed below the temperature of 200°C could be provided by concentrating solar thermal energy systems. For the remaining 66.5% of the process heat demand could be augmented in part by a solar thermal energy system at a lower temperature as a preheat.

In general, as we discussed about the design of commercial solar thermal energy systems, the basic building block in the industrial process heat system is the collector, and therefore is the most significant part of the design of a solar process heat system. Among the major variables affecting the choice of collectors are: required amount of process energy, process energy demand patterns, required process terminal temperatures, available solar energy, collector performance, system performance, and installed system cost. The accepted general procedure for designing a solar process heat system is to first conceptualize the solar system. This conceptualization would show a flow schematic for the solar thermal energy system proposed for this industrial process heat application. From the annual data on the process heat system, determine loads, load patterns, and temperature patterns needed. Using common radiation tables, determine the available solar radiation and relevant ambient temperature for the location of the design. Using the collector manufactured data find the collector efficiency relationship of the selected collectors. Develop a paper model which will allow the system performance to be calculated. Review and evaluate this model to determine performance for different collector sizes, configurations, and orientation. Using an economic optimizing procedure, determine the best system configuration. Repeat the same evaluation process for several alternative collectors determining which has the greatest cost benefits or gives the greatest ratio of return. The procedure described for the evaluation of a solar process heat system is both costly and time consuming but is normally carried out by a design engineer, by design engineering firms, or solar application firms for industrial process heat projects. Because of this cost, often only preliminary assessment is needed, perhaps to determine whether further investigation is warranted or if an idea should be discarded. In such cases, a number of simplifying assumptions can be made, allowing most of the desired information to be presented in the form of either charts of table.

Additional reading on solar process heat systems would be recommended in the Solar Energy Handbook by Kreider and Kreith, Chapter 21, entitled, "Solar Process Heat Systems".

STUDENT EXERCISES

1. From the discussion above, produce a checklist for a field trip to observe an industrial use of solar process heat.

2. Take a field trip to industrial sites in your neighborhood which use industrial process heat. Examples might be laundries, car washes, bottling companies, food processing plants. Using your checklist above, design a solar energy system to fit the industrial site visited. This is not an easy task. Make it as detailed an assessment as your instructor will allow.

Note: As a review of how to size a solar system, read the following selection from Tapping the Sun: An Arizona Homeowner's Guide to Buying a Solar Domestic Hot Water System, Dr. Mary R. Anderson and Mr. John A. Kimball, Arizona Solar Energy Commission, Phoenix, AZ, 1980. It is reprinted by permission from Ms. Pat Wing. Even though it deals with domestic hot water system sizing, the principles can be applied to non-residential applications as well.

Chapter VI

SDHW SYSTEM SIZING

In order to determine the best collector and storage tank size, one has to first find out how much hot water the family uses per day. Consideration should also be given to sizing the system for the home rather than for the family. This would provide ample hot water supply for future homeowners.

The Hot Water Demand

In Arizona, it is assumed that the average family of 4 uses about 80 gallons per day--about 20 gallons per person. It is important to accurately determine the hot water use for proper system sizing. Of course, the demand varies from household to household. For this reason, Table VI-1 presents the typical amounts of hot water required for different uses. The data was obtained from Consumer Reports magazine, appliance servicemen, and by timing personal hot water usages.

By far the greatest use of hot water in the home takes place in bathing. In only one week one person taking a daily 10 minute shower will consume 240 gallons of 130 F water. The second largest consumer of hot water in the home is the washing machine. Washing four loads of laundry in an 18 pound clothes washer using a Hot Wash/Warm Rinse cycle will require 144 gallons of hot water. Then comes the dishwasher. One dishwashing cycle a day a week uses 105 gallons of hot water. From here the gallons per use drops but the list of remaining uses lengthens.

It takes about 9 cents worth of electricity to heat 10 gallons of water. If one 18-pound load of clothes is washed daily, a family could save about $90 a year at 6 cents per KWH just by switching from the Hot Wash/Warm Rinse to the Warm Wash/Cold Rinse cycle. Energy-saving showerheads can also significantly reduce hot water use without sacrificing individual comfort. Flow restrictors added to faucets can reduce overall water usage as well as hot water usage.

SOURCE: <u>Tapping the Sun: An Arizona Homeowner's Guide to Buying a Solar Hot Water System</u>, Dr. Mary R. Anerson and Mr. John A. Kimball, Arizona Solar Energy Commission, Phoenix, AZ, pp. VI-1 through VI-16. Reprinted by permission from Ms. Pat Wing, Arizona Solar Energy Commission.

Table VI-1
Typical Hot Water Requirements

Use	Hot water Required (Gallons per use)		
1. Clotheswashing Machine	14 lb. machine		18 lb. machine
a. Hot Wash/Hot Rinse	38		48
b. Hot Wash/Warm Rinse	28		36
c. Hot Wash/Cold Rinse	19		24
d. Warm Wash/Cold Rinse	10		12
2. Dishwasher Machine	15		
3. Personal Hygiene			
a. Showering (ave. shower is 5 min.)	140°	130°	120°
1) Without Energy-saving Showerhead	3/min.	3.4/min	4/min.
2) With Energy-saving Showerhead	1.5/min.	1.7/min.	2/min.
b. Tub Bathing (full tub)	15	17	20
c./d. Wet Shaving/Hair Washing	2-4	2.3-4.5	2.7-5.3
e. Hand & Face Washing	1-2	1.2-2.3	1.3-2.7
4. Miscellaneous Household Uses			
a. Washing Clothes by Hand	1-2	1.2-2.3	2.7-5.3
b. Washing Dishes by Hand	4	4.5	5.3
c. Preparation of Dishes for Dishwasher	1-2	1.2-2.3	2.7-5.3
d. Miscellaneous Housecleaning	2.5	2.8	3.3
e. Food preparation using hot water	3	3.4	4

Example 1.

The Jones family consists of Mr. and Mrs. Jones and their two children, a teenager and a pre-teen. They live in a home having an 18 pound clothes washer and a dishwasher. The father takes 7 minute showers daily, The mother takes 4 minute showers daily, washing her hair separately twice a week. The teenager showers daily for 5 minutes, washing his hair in the shower as necessary. The pre-teen takes 4 (4-minute) showers a week, if the family is luck. The water tank thermostat is set at 140 F.

Using the hot water requirements from Table VI-1, we calculate first the weekly hot water usage from which we can determine the average daily hot water demand.

Example Worksheet 1

Estimating Daily Hot Water Demand for the Jones Family

Use	Weekly No. of Uses	X	Gal./Use	=	Weekly Total
1. Clotheswashing					
a. Hot Wash/Hot Rinse	0	X		=	0
b. Hot Wash/Warm Rinse	0	X		=	0
c. Hot Wash/Cold Rinse	0	X		=	0
d. Warm Wash/Cold Rinse	3	X	12	=	36
2. Dishwasher Machine	7	X	15	=	105
3. Personal Hygiene					
a. Showering	128 minutes	X	3	=	384
b. Tub Bathing	0	X		=	0
c. Wet Shaving	7	X	2	=	14
d. Hair Washing	2	X	4	=	8
e. Hand & Face Washing	50	X	1	=	50
4. Miscellaneous Household Uses					
a. Washing Clothes by Hand	1	X	2	=	2
b. Washing Dishes by Hand	0	X		=	0
c. Preparation of Dishes for Dishwasher	7	X	1	=	7
d. Misc. Housecleaning	0	X		=	0
e. Food Preparation using hot water	0	X		=	0
					606 Weekly Total

G = Daily Hot Water Use = 606 (Weekly Total) ÷ 7 = 86.5 (Daily Total in Gallons)

The weekly usage averages out to a daily demand of 86.5 gallons. This averages out to about 22 gallons per person. Had the Jones family installed energy-saving shower heads, the daily per person use would only have been 15 gallons! For this family, The energy-saving shower heads could have saved over $70 per year. A good plusating energy-saving shower head which regulates flow to 1½ gallons per minute costs about $25. Reduced water usage will also save money on a solar water system since less collector area will be needed and a smaller water tank will be required.

Now calculate your own daily hot water usage on the following worksheet:

WORKSHEET 1

Estimating Daily Hot Water Demand

Use	Weekly No. of Uses	X	Gal./Use	=	Weekly Total
1. Clotheswashing					
a. Hot Wash/Hot Rinse		X		=	
b. Hot Wash/Warm Rinse		X		=	
c. Hot Wash/Cold Rinse		X		=	
d. Warm Wash/Cold Rinse		X		=	
2. Dishwasher Machine		X	15	=	
3. Personal Hygiene					
a. Showering	minutes	X		=	
b. Tub Bathing		X		=	
c. Wet Shaving		X		=	
d. Hair Washing		X		=	
e. Hand & Face Washing		X		=	
4. Miscellaneous Household Uses					
a. Washing Clothes by Hand		X		=	
b. Washing Dishes by Hand		X		=	
c. Preparation of Dishes for Dishwasher		X		=	
d. Misc. Housecleaning		X		=	
e. Food Preparation		X		=	
					Weekly Total

G = Daily Hot Water Use = ______ ÷ 7 = ______
Weekly Total ÷ 7 = Daily Total in Gallons

Sizing the Solar Hot Water Storage Tank

The solar tank should be sized to provide for about one day's hot water demand. Storage tanks come in standard sizes of 40, 52, 66, 82, 100 and 120 gallons. Recently, some manufacturers have started making 100-gallon tanks suitable for solar use. Figure VI-1 can be used to determine the necessary storage tank size. To do this find your daily hot water demand at the left hand side of the graph and go to the corresponding tank size to the right. If the tank size needed is between steps, the larger tank should be selected to ensure adequate quick-recovery backup and to improve the system performance (up to 7%).

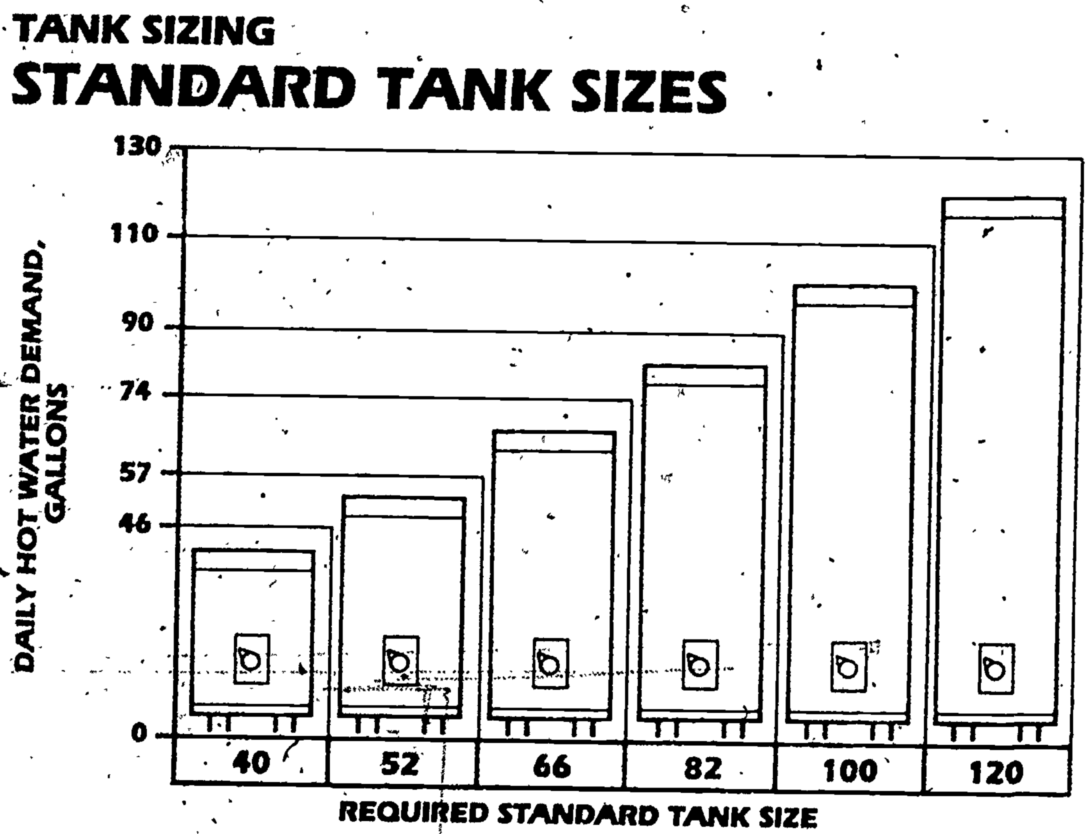


Figure VI-1 STORAGE TANK SIZING FOR SOLAR SYSTEM

Example 2.

From Figure VI-1, the Jones family with a daily demand of 86.5 gallons, would look for a 82-gallon storage tank.

A. Storage Ratio

The proper sizing of the solar hot water storage tank to the collector area is a key element for efficient and effective system performance. For most systems, this ratio is between 1.5 and 2.0 gallons of hot water storage for each square foot of collector area.

An undersized storage capacity results in raising the water temperature to its peak level too early in the day. Consequently the system is prematurely saturated. This can prevent the efficient collection of additional available solar energy during the rest of the day.

An oversized storage capacity results in a slower increase in water temperature during the day. Although the collectors operate efficiently, they may have difficulty in raising the temperature of such a large volume of water to the desired temperature. This requires the backup system to boost the temperature to the temperature level desired causing a loss of utility savings.

The Solar Collectors

Solar collectors must be sized properly to obtain an efficient system. To determine the required collector area, the hot water demand must be known. The phrase "collector area" means the gross collector area, which is the product of the length and width of the collector box.

The following are rule of thumb sizing figures for solar collectors. They assume a single-cover collector with a nonselective absorber plate, oriented south, and, in Arizona, tilted at an angle of approximately 45°.

Family or House Size	Collector Area/Sq. Ft.	
	Phoenix	Flagstaff
Family of 2 or 1-2 bedrooms	22-29	26-34
Family of 3 or 2 bedrooms	33-44	38-51
Family of 4 or 3 bedrooms	44-59	51-68
Family of 5 or 4 bedrooms	55-73	64-85
Family of 6 or 5 bedrooms	66-88	77-102

The remainder of this chapter presents a more accurate method of determining collector area.

To do this it is important to understand how to describe the performance of a solar collector. The efficiency of the collector is a measure of its ability to absorb the sun's energy and to transfer this heat energy to the collector fluid. The most popular method of determing the efficiency of solar collectors in the ASHRAE Standard 93-77 test method. The efficiency for flat plate collectors is given in terms of an equation. It is rather difficult for the average homeowner to follow. It has been included for those who wish to thoroughly cover the subject. For those who wish to skip this more technical aspect of sizing, they should move on to Collector Sizing From Graphs.

$$E = A - B\,(TF - TO)/I$$

where E = Thermal efficiency of the solar collectors,

A = Intercept on the vertical axis and is a measure of the ability of the collector to absorb solar energy and to transfer the heat to the collector fluid, (dimensionless),

B = Slope of the line and is a measure of the ability of the collector to transfer the heat to the collector fluid and its ability to reduce heat losses from the collector box to the ambient air, (Btu/[hr-ft^2°F]),

TF= Collector inlet fluid temperature and is basically the operating temperature for the collector, (°F),

TO= Outside air temperature, (°F),

I = Solar irradiation incident on the collector, (Btu/[hr ft^2° F]).

Inspection of this equation shows that an increase in the collector operating temperature, T_F, will lower the collector efficiency. A decrease in the solar irradiation will also decrease collector efficiency. Ideally, the collector should have a high value for A and a low value for B. Typical values are:

	A		B (Btu/[hr – ft^2° F])
High	0.65-0.85	High	0.90-1.5
Low	0.50-0.65	Low	0.50-0.90

The ASHRAE 93-77 data is usually available from most collector manufacturers.

Collector Sizing From Graphs

The ASHRAE Standard 93-77 test method for determining collector efficiency is also presented in the form of an easy to understand graph. A sample graph, giving the efficiency of a collector at various operating conditions is shown below in Figure VI-2. Operating conditions means the sunlight available, air temperature and inlet water temperature to the collector. Since these conditions change constantly throughout the day, there is no single efficiency value for a collector. However, there is a certain normal range of operating conditions which can be looked at and used to compare collectors.

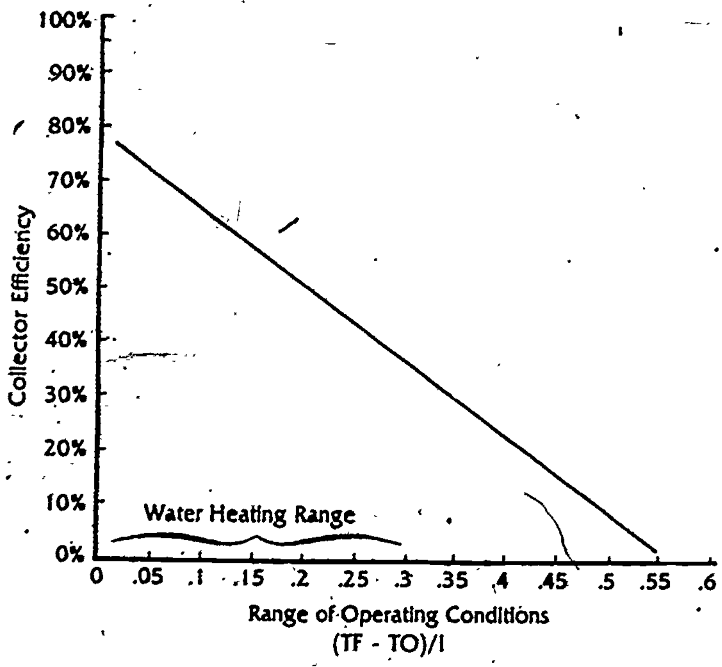


Figure VI-2 **ASHRAE 93-77 COLLECTOR EFFICIENCY CURVE** illustrating the importance of selecting the collector for its efficiency at the operating conditions for the given application.

It is important to compare the efficiencies of collectors for only the range of operating temperatures in which they will be required to perform. For domestic water heating, only the range of operating temperatures from .0 to .3 should be considered. Beyond this point operating conditions become too extreme. However, some concentrating collectors can effectively operate in this range. For example, Figure VI-2 shows a typical efficiency curve for a solar collector.

The prodedure for sizing the collector is outlined below in several steps, Worksheet 2 should be used in this procedure. Also, see the example worksheet following this discussion.

The proper size of the collector area can be estimated as follows:

Basic Collector Area = A (from Step 1 & 2)

For Phoenix and Tucson using the basic collector area A is sufficient.

In other Arizona locations or where severe mounting problems exist or if you are willing to turn your thermostat set temperature down below 140°, a detailed collector area determination should be made.

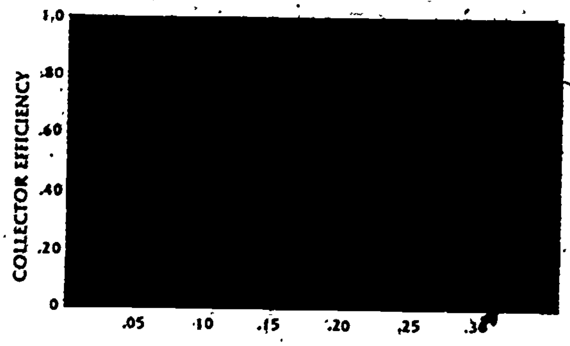
Detailed Collector Area = A x W x T x O x S

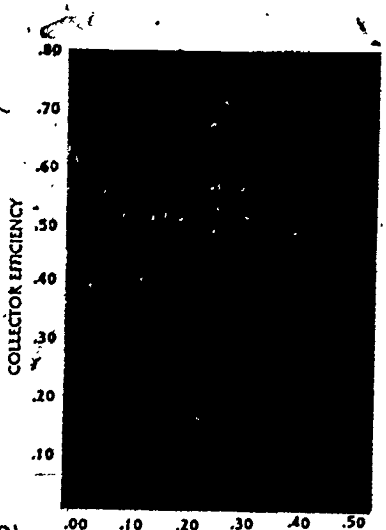
where A = Basic Collector Area (from Step 1 & 2)
W = Weather factor,
T = Tilt factor,
O = Orientation factor,
and S = Water Set Temperature factor

Basic Collector Area

– Step 1. (G and F) Estimate the family daily hot water demand G (see worksheet 1) and select the desired fraction of the hot water to be supplied from solar (called F). .82 is suggested for Arizona's desert regions and .75 for higher elevations. (See Table VI-3 for a breakdown of monthly solar fractions for desert regions.

– Step 2. (A) To determine the basic collector area A, Figure VI-3 should be used. Before using this graph a determination of the collector performance desired or being considered should be made. As has been pointed out by Figure VI-2 the average performance or efficiency of a collector can be determined by examination of a collector efficiency curve. Since the collector operating range for solar water heating systems lies between .0 and .3 on the horizontal axis of this curve, halfway or .15 would give the average collector efficiency. For example, the following are two examples of an efficiency curve from the promotional literature of two company's collectors. Looking at .15 on the horizontal axis and going up to the efficiency curve, we see that the collector on the left has an average efficiency of .68 or 68% and the collector on the right has an average efficiency of .55 or 55%. A rating of the collector's efficiency can then be made.





Efficiency		Efficiency Rating (for use of sizing graph Figure VI-3)
65% and above	=	High
50% to 65%	=	Average
50% and below	=	Low

Once the collector has been rated as high, average or low, Figure VI-3 can be used to determine the basic collector area (A). Using the preferred solar fraction (F) on the left side of the graph and choosing a collector with the desired rating, determine (X) on the horizontal axis. When this number, (X) is multiplied times (G) the gallons of hot water used per day, the result is (A) the basic collector area.

$$A = X \times G,$$

where X = Collector area to hot water daily demand ratio,
and G = Hot water used in gallons per day.

The answer will be in square feet, and it indicates the area required for properly tilted and oriented collectors in the Phoenix and Tucson areas and for providing 140°F water. For collectors not satisfying these conditions, adjustments can be made in detailed collector sizing Steps 3 thru 7.

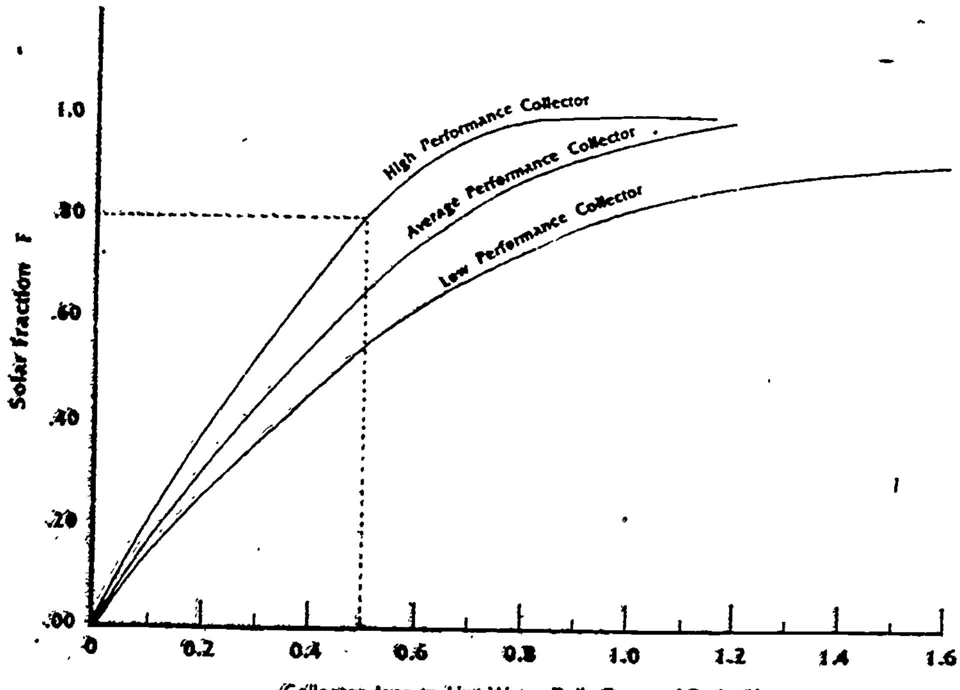


Figure VI-3 SOLAR COLLECTOR SIZING GRAPH

Table VI-2
Effect of Weather

City	Weather Factor (W)		
Collector Rating:	High	Average	Low
Flagstaff	1.14	1.16	1.19
Phoenix	1.00	1.00	1.00
Prescott	1.04	1.06	1.08
Tucson	1.02	1.02	1.02
Winslow	1.11	1.12	1.13
Yuma	0.96	0.96	0.96

Step 3. (W) Select from Table VI-2 the weather factor (W) of the city nearest the house.

Step 4. (T) Determine the latitude from Figure VI-4. If the collector tilt is going to be latitude, plus 10°, the tilt factor is 1.0. If not, determine from Figure VI-5 the tilt multiplication factor (T).

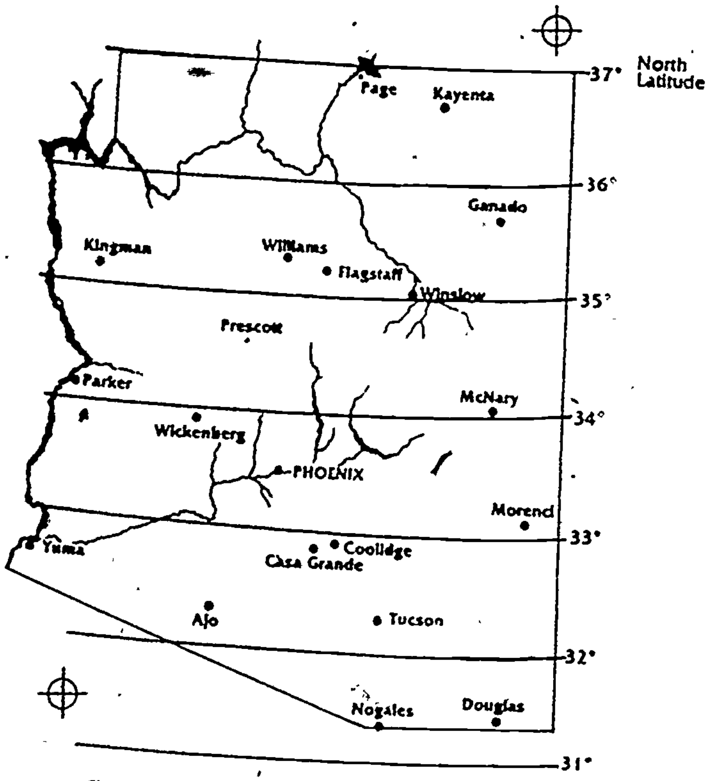


Figure VI-4 LATITUDE LINES OF ARIZONA

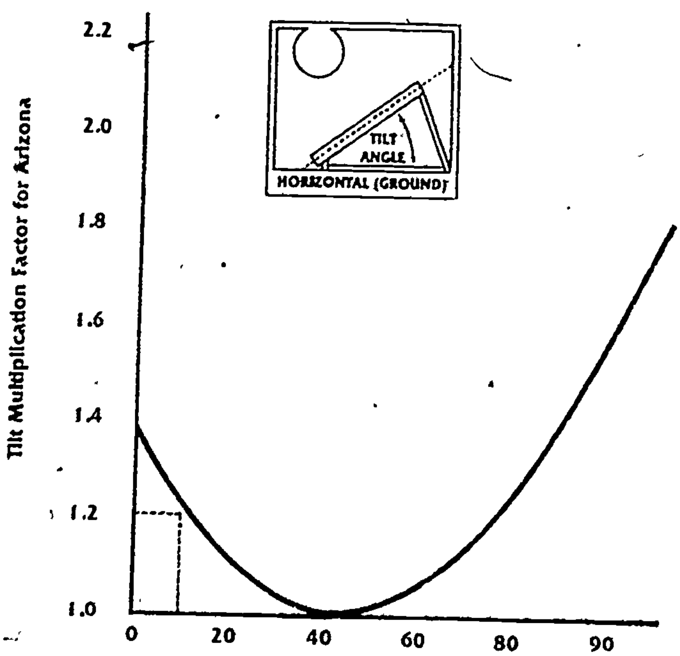


Figure VI-5 EFFECT OF COLLECTOR TILT

(The optimum collector tilt is latitude plus 10° i.e. Phoenix latitude = 34° plus 10° = 44°)

— Step 5. (O) If the collector orientation is going to be south, the orientation factor is 1.0. If not, determine from Figure VI-6 the orientation multiplication factor (O).

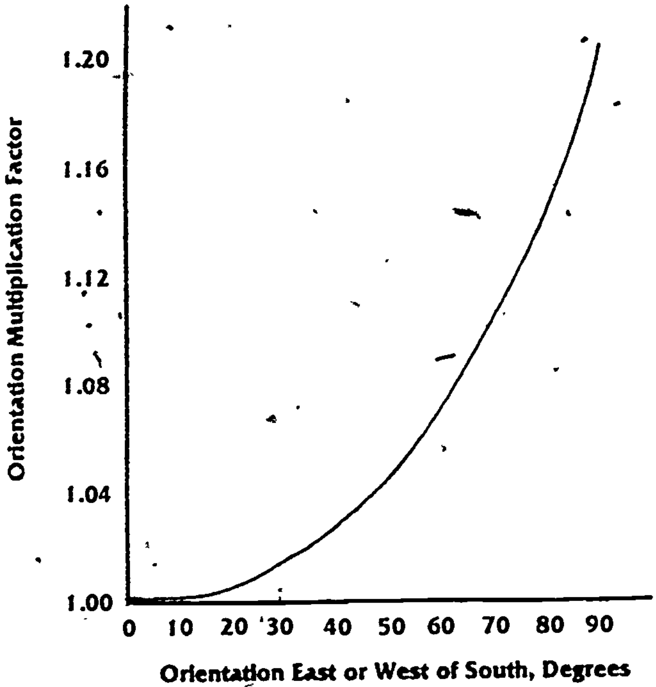


Figure VI-6 EFFECT OF NON-SOUTH COLLECTOR ORIENTATION

— Step 6. (S) If the water set temperature is 140°F, the water temperature factor is 1.0. If not, determine from Figure VI-7 the water set temperature multiplication factor (S).

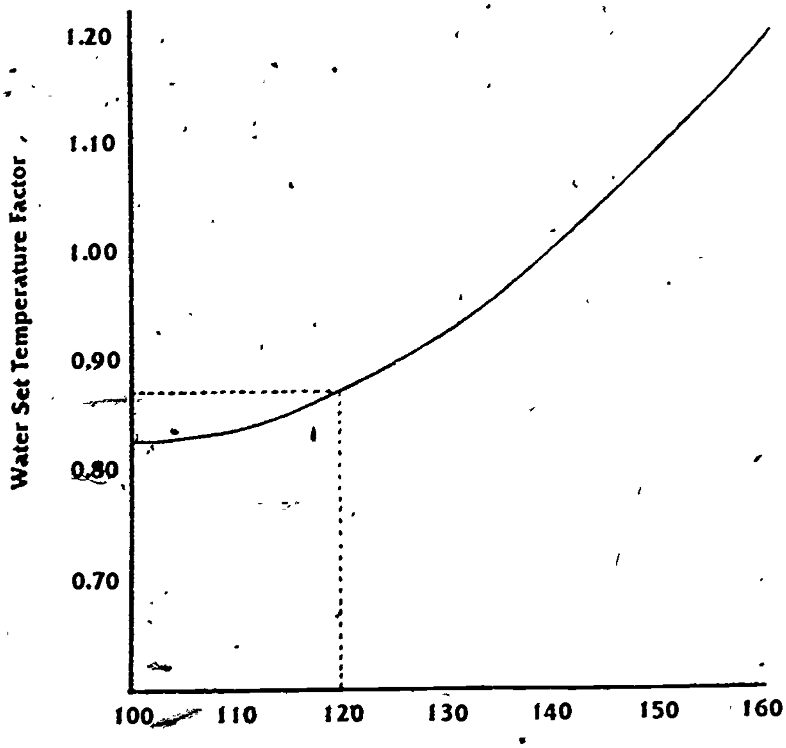


Figure VI-7 EFFECT OF WATER SET TEMPERATURE

Table VI-3

Typical Monthly Fraction of Hot Water Demand Met by SDWH System in Arizona Desert Area.

Month	Fraction Hot Water Demand Met By SDHW System
January	.66
February	.76
March	.83
April	.89
May	.88
June	.86
July	.85
August	.93
September	.99
October	.92
November	.77
December	.64
Year Average	.82 approximately

Step 7. Determine the final collector area required as:

Detailed Collector Area = A x W x T x O x S,

Select a number of collector panels so that their combined area equals or slightly exceeds the calculated final area. If a heat exchanger is used in the system, the collector area should be increased 10% to 15%.

The steps and graphs are now described in detail. See the example at the end of this discussion for further clarification.

See Step 1. It should be recognized that when an F, the fraction of the hot water demand to be met by the solar system, is selected, the value is an annual average that will vary from month to month. The above table gives a typical monthly fraction of the energy to be supplied by solar that could be expected from a system meeting approximately 82% of the yearly hot water demand.

Step 2. Collector efficiency varies from manufacturer to manufacturer. Figure VI-3 presents collector efficiency curves obtained from the F CHART method by using data obtained from ASHRAE Standard 93-77 tests and the 1980 U.S. DOE Solar Collector Test Program for 163 different collectors. The water set temperature is 140°F. and the supply temperature is 60°F. Storage is 1.5 gallons per square feet of collector area.

Example 3 in this chapter describes how to read the graphs. The dotted lines on Figure VI-3 show that for an 80% solar system (F = .80) one would need .50 square feet of high performance collector for every gallon of hot water per day of demand. Thus, for the Jone's family of four with a hot water demand of about 86 gallons per day, one needs 86 x .50 = 43 square feet of high performance collector.

Step 3. The amount of sunshine and the local air and water temperature are the three important variables affecting solar collector performance.

Step 4. The best collector tilt angle for water heating is the location latitude plus

10°. This angle maximizes annual amount of sunshine falling on a flat-plate tilted collector fixed in position throughout the year. However, the effect of tilt angle variation is small so long as it is within reason. This is indicated by the tilt mutiplication factor graph for Figure VI-5. This graph is valid for all locations in Arizona. The dotted lines show that for a roof pitch of 11 degrees (corresponds to a pitch of 1 in 5), the tilt multiplication factor is only 1.2.

Step 5. The collectors should normally face south. If the collector cannot face south due to roof orientation or other structural reasons, then the collector area must be increased by the orientation factor shown in Figure VI-6. The dotted lines in Figure VI-6 show that for an orientation 30 degrees east or west of south, the orientation factor is only 1.01.

Step 6. The system calculations assumed that the water set temperature is 140°F. Significant savings can be made if the user can satisfy the hot water requirements using water at a lower temperature. For example, if the water temperature can be set at 120°F, there would be a 13% reduction in required collector area. This is illustrated by the dotted lines in Figure VI-7.

Example 3.

The Jones family of four uses 86.5 gallons of hot water per day. We wish to calculate the collector size necessary to supply 80% of the hot water at 140°F. Assume that the collectors will face south and be tilted at the proper tilt angle. Perform the calculations for Phoenix.

We assume that a high performance collector is used. 80% solar means F = .80. Since the location is Phoenix, the collector tilt and orientation are optimum, and 140°F water is desired. This example will only require determining the basic collector area (A) from Figure VI-3. Go to Figure VI-3. On the vertical (marked F) axis of the graph, find the point corresponding to F = .80 and draw a horizontal line from that point until it meets the curve marked "High". Draw a vertical line down from the curve and find the point where the vertical line intersects the horizontal axis (X). Read that point as X = .50.

This X = .50 means that for every gallon per day of hot water demand, .50 square feet of high performance collector will be needed to supply 80% of the demand from solar in Phoenix. Since the demand is 86.5 gallons of hot water per day, 86.5 x .50 = 43.2 sq. ft. of collector will be needed.

This example is now calculated on a work sheet.

Example Worksheet 2
(80% average system for 140°F water in Phoenix)

A. Determine storage tank size from Figure VI-1.
Tank Size is 82 gallons.

B. Determine collector size.

1. Estimate G on Worksheet 1. G = 86.5
Select F. F = .80

2. Select a collector from Figure VI-3 and determine X. X = .50

Determine A $\frac{.50}{X} \times \frac{86.5}{G} = \frac{43.2}{A}$ A = 43.2

Generally, if the solar system is in the desert region of the state and the desired water temperature is 140°, the basic collector area (A) may be used. If not, then steps 3 thru 6 should be completed.

---

3. Determine weather multiplication factor from Table VI-2. W = 1.0

4. Determine tilt multiplication factor from Figure VI-5. T = 1.0

5. Determine orientation multiplication factor from Figure VI-6. O = 1.0

6. Choose water set temperature multiplication factor from Figure VI-7. S = 1.0

Detailed Collector Area = $\frac{43.2}{A} \times \frac{1}{W} \times \frac{1}{T} \times \frac{1}{O} \times \frac{1}{S}$ = 43.2 Sq. Ft.

WORKSHEET 2
Determining Tank and Collector Size

A. Determine storage tank size from Figure VI-1 using G determined from Worksheet 1.

Tank Size is __________ gallons.

B. Determine collector size.

1. Estimate G on Worksheet 1. G = ________
   Select F. F = ________
2. Select a collector from Figure VI-3 and determine X. X = ________

Basic Collector Area = ______ x ______ = ______ A = ______
X G A

Generally, if the solar system is in the desert region of the state and the desired water temperature is 140 , the basic collector area, (A) may be used. If not, then steps 3 thru 6 should be completed.

---

3. Determine weather multiplication factor from Table VI-2. W = ______
4. Determine tilt multiplication factor from Figure VI-5. T = ______
5. Determine orientation multiplication factor from Figure VI-6. O = ______
6. Choose water set temperature multiplication factor from Figure VI-7. S = ______

Detailed Collector Area = _____ x _____ x _____ x _____ x _____ = ________
A W T O S Sq. Ft.

NON-RESIDENTIAL APPLICATIONS AND FUTURE TECHNOLOGY

PHOTOVOLTAIC POWER SYSTEMS

STUDENT MATERIAL

NON-RESIDENTIAL APPLICATIONS AND FUTURE TECHNOLOGY

Photovoltaic Collectors and Systems

UNIT 1. Elements of Photovoltaic Power Systems

As in most solar energy conversion systems, photovoltaic effect is not new. Pholovoltaic effect was discovered in 1839. The first solid state photovoltaic device was manufactured in 1876. It was not, however, until the early 1960's that utilization of this approach to solar energy conversion gained any significance. It was the early 1960's when solar energy conversion provided by photovoltaic systems powered most of the spacecraft launched by all nations. In this space related application, solar energy has been found to be the most suitable energy source. Photovoltaic conversion devices have proven themselves to be a key lightweight, highly reliable power supply system.

The technical feasibility of utilizing photovoltaic solar energy conversion systems has been well established. The remaining task for the industry is to attain economic feasibility for large scale photovoltaic conversion system installations. In general, this means reducing the initial cost of the production of the photovoltaic system to a point at which it can generate electrical energy competitively with the non-renewable source of energy, both fossil and nuclear fuels. Thus, today the majority of the research and development currently in progress is centered on the task of photovoltaic cell cost reduction.

When discussing photovoltaics, it is important to think of the photovoltaic solar energy conversion system as a system rather than just a solar cell. The solar energy conversion system converts solar energy to electrical power to satisfy demand of a given load. Such loads may range from small single purpose devices, such as navigation lights, to single family residences, or commercial and public buildings, or industrial plants of various sizes, to the potential of an entire community network. Each load generally requires power delivery on demand, at a fixed voltage and in some cases, at a controlled frequency or phase. Consequently, the solar energy conversion system typically contains in addition to the solar collector, a voltage, electrical energy storage system, an inverter, and possibly, depending on the size, some additional subsystems. Nonetheless, the collector forms the heart of the system and should be the key factor in the design of any solar energy conversion system. The process of the photovoltaic energy conversion system takes place in a thin stationary layer to material when light falls on it. Most of the materials used are solids, but they do not have to be solid; they can be liquid. In this conversion process, electrical charges are freed and made to flow as current through an outside circuit and to electrical load where they can perform work. The current will flow only as long as the light falls on the device. No storage mechanism exists in the solar energy conversion system. If energy storage is required it will have to be provided as a separate subsystem. As with most photovoltaic devices, response is to a broad range of light waves and colors. This response to wave length range can be tailored to encompass the major part of the solar spectrum.

The basic photovoltaic system can be identified by one of three categories: small to medium size, ground-based centralized systems, and central systems. The small to medium size pholovoltaic systems are dedicated to individual loads, often with the convertors attached to or incorporated into a building structure. Their array sizes range from about 40 to 10,000 meters squared. With the average daily capacities ranging from 15 to 10,000 KWH, the system gets its name. Ground based centralized systems are large photovoltaic collectors serving a distribution system or a single, large consumer having an array range of various sizes from about 1,000 meters squared to 50 kilometers squared. The average daily capacities for the ground base central system ranges from 500 to 50,000 KWH.

The last classification of photovoltaic systems would be the central ground stations and subsequent distribution. These systems would have a design capacity of 240,000 KWH daily. The central system in space is now in the study phase and is not expected to be in operation within this century.

The first two systems which are dedicated to a single user or small community, would be considered on-site power systems. This application of photovoltaic arrays locates the generator at the place of the load thus reducing the need for energy transmission and distribution equipment and the associated losses in cost of that equipment.

READ: Wolf, Martin, "Photovoltaic Solar Energy Conversion Systems", university of Pennsylvania, Philadelphia, PA, in Kreider and Kreith, Solar Energy Handbook, McGraw-Hill, 1981, Chapter 24.

SUMMARY OF: "Photovoltaic Solar Energy Conversion Systems"

This article is the key reading of this section on photovoltaic conversion. It is detailed and precise as the state of the art exists today. The topic of photovoltaic is ever-changing due to the rapid break throughs being made. Therefore, even if this article is important and an overview of the topic, it must be supplemented by additional, constant update and review of the literature.

This article is outlined in the following manner:

I. Introduction.
   A. History.
   B. Principles of Photovoltaic Conversion.
   C. Basic Photovoltaic Systems.
II. The Photovoltaic Solar Energy Conversion Device.
   A. The Mechnisms of Device Operation.
   B. The Light-Generated Currents.
   C. Averaged Analysis.
   D. Charge Current Density.
   E. The Current-Voltage Characteristic.
III. Performance Limitations and Possible Improvements.
   A. Reflective Losses.
   B. Incomplete Absorption.
   C. Partial Utilization of the Photon Energy.
   D. The Voltage Factor.
   E. The Curve Factor.
   F. Series Resistance Losses.
IV. Conversion Efficiency Limits.

NON-RESIDENTIAL APPLICATIONS AND FUTURE TECHNOLOGY

Photovoltaic Collectors and Systems

UNIT 2. Technology of Photovoltaics

READ: Maycock, Paul D., and Edward N. Stirewalt, Photovoltaics: Sunlight to Electricity in One Step, Brick House Publishing Co., Andover, MA, 1981, Chapter 2.

SUMMARY OF: Chapter 2.

The photovoltaic phenomenon--the process by which light is converted silently and directly into electricity, without the elaborate machinery we usually associate with the generation of electricity--is elegant. It is certainly far less complicated than an atomic reactor, or, for that matter, even a conventional coal- or oil-fired plant. A review of the science underlying photovoltaics will help to explain why photovoltaics is at once safe, clean, durable, reliable, energy-efficient, and increasingly socially and economically attractive. A background in high school or college physics is quite adequate to appreciate the nature of the processes involved.

The outline for Chapter 2 is as follows:

I. Light.
II. Single Crystal Silicon.
III. How a Photovoltaic Cell Works.
IV. Polycrystalline Silicon.
V. Amorphous Silicon.
VI. Other Kinds of Solar Cells.

NON-RESIDENTIAL APPLICATIONS AND FUTURE TECHNOLOGY

Photovoltaic Collectors and Systems

UNIT 3. Options for Improving Photovoltaics

READ: Maycock, Paul D., and Edward N. Stirewalt, Photovoltaics: Sunlight to Electricity in One Step, Brick House Publishing Co., Andover, MA, 1981, Chapter 3.

SUMMARY OF: Chapter 3.

If price were no object photovoltaics would already be widely used as a clean, safe, reliable, silent source of electric power. Price is indeed an object, however, as anyone who has studied his of her heating or electric bill and searched for alternative energy sources will agree. The price of photovoltaics is intertwined with the technology for producing photovoltaic cells. Genuinely economical photovoltaic systems depend on the successful development of new production methods that capitalize on economies of scale through automation, and the development of more energy-efficient collectors. Soon to be cost-competitive, photovoltaics can be expected to reorder the energy equation around which our economy is structured.

Photovoltaics becomes economic at different unit costs, depending on the application and relevant variables, such as climate, tax status of the owner, cost of money, and the price of utility-generated electricity. For a number of reasons, we use the figure of $.70 per installed Watt of peak capacity for the array as a benchmark at which photovoltaics becomes generally competitive for residential applications in the United States (all prices are in 1980 dollars).

The following is an outline of Chapter 3:

I. Purifying Silicon.
   A. Base Option: Single Crystal Silicon.
   B. Option 2: Silicon Sheet.
   C. Option 3: Ingot Casting of Nearly Single Crystals. (Polycrystalline Silicon)
   D. Option 4: Silicon on Ceramics.

II. Some Longer Shots: Materials and Designs.
   A. Option 5: Non-Silicon Thin Films.
   B. Option 6: Concentrator Designs.
   C. Option 7: Amorphous Materials.

III. Experimental Cell Types.

IV. A Technology Teeming with Possibilities.

NON-RESIDENTIAL APPLICATIONS AND FUTURE TECHNOLOGY

Photovoltaic Collectors and Systems

UNIT 4: Applications for Photovoltaics

READ: Maycock, Paul D., and Edward N. Stirewalt, Photovoltaics: Sunlight to Electricity in One Step, Brick House Publishing Co., Andover, MA, 1981, Chapter 4.

SUMMARY OF: Chapter 4.

History is responsible for the mistaken and widely held notion that photovoltaics is a high cost, exotic technology with very limited and specialized uses. In the rush to loft the American respose to the Soviet Union's Sputnik, Army Signal Corps engineers at Fort Monmouth, NJ, obtained enough design latitude to power the Vanguard I's 5-milliwatt radio transmitter with commercially available solar cells. On March 17, 1958, six small arrays containing 108 silicon chips went into space. But the full implications of using solar power did not sink in until after the launch: with no cutoff device, Vanguard's signals fully and needlessly occupied a radio band for about eight years. The next 22 U.S. satellites went up with electrochemical batteries, but in late 1959 Explorer VI was fitted with 8,000 1- by 2-cm silicon cells, which produced ablut 15 watts of power.

Except for a few nuclear reactors, silicon solar cells remained the chosen power source in space. By 1975, the National Aeronautics and Space Administration (NASA) was using nearly a million cells a year. Array sizes grew: Nimbus, a weather satellite launched in August 1964, carried a 500-watt array; the Orbiting Astronomical Observatory carried a 1,000-watt array; some Air Force satellites produced 1.5 kilowatts. Only engineering considerations of balance, rotation, and stress now seem to present limits to the size of photovoltaic arrays in space. A manned space station plan calls for a 100-watt array.

On earth, solar cell production grew rapidly during the early 1960's. Companies such as Hoffman (now Applied Solar Energy), Helioteck, International Rectifier, RCA, and Texas Instruments entered the field. By 1970, only Hoffman and Helioteck remained in the photovoltaic business. Total sales leveled off at about 80 kilowatts per year, at an average cost of $100-200 per watt.

Success in space led to renewed speculation among photovoltaic producers over potential terrestrial uses. By 1970, concerns about finite fossil suel supplies and about pollution from excess heat, combustion by-products and radiation from other energy sources began to place photovoltaic power generation in an ever more favorable light.

The following is an outline of the remainder of the Chapter 4:

I. Stand-Alone Applications.
II. Grid-Connected Distribution Applications.
   A. How Much Electricity Does Your Home Use?
   B. Photovoltaics for New Housing.
   C. The Cooperating Grid.
III. Central Utility Applications for Photovoltaic Systems.
IV. Commercialization Begins.

NON-RESIDENTIAL APPLICATIONS AND FUTURE TECHNOLOGY

Photovoltaic Collectors and Systems

UNIT 5. Economics of Photovoltaics.

READ: Maycock, Paul D., and Edward N. Stirewalt, Photovoltaics: Sunlight to Electricity in One Step, Brick House Publishing Co., Andover, MA, 1981, Chapter 5.

SUMMARY OF: Chapter 5.

The economic characteristics of photovoltaic use can be considered from the perspectives of the individual user, the photovoltaic manufacturer, the utilities manager, and the other players in the worldwide mixed economy in which solar cells are just one of many competing responses to the current energy situation. The changeover to photovoltaics and other renewable energy sources will accelerate as costs decline and as the nation's physical plant is steadily replaced. Photovoltaics will function as a technological "substitutions" on the supply side of a domestic and world economy, and the magnitude of such a substitution is great: analogies are, say, the steamship for the square rigger, or the car for the horse.

The substitution of photovoltaics for conventional electrical sources will proceed over time to the limit of usefulness, when we can expect another **dynamic** equilibrium to be established. Subsequently photovoltaic use is likely to fluctuate marginally in response to microeconomic considerations.

How rapidly the substitution takes place and at what level market equilibrium will occur depend on two key factors--the federal government's policy commitments to alternative energy sources and publio interest in photovoltaics.

The following is an outline of the remainder of Chapter 5:

I. The Interest Groups.
   A. Users.
   B. Photovoltaic Manufacturers.
   C. Photovoltaic Distributors.
   D. Local Governments.
   E. Utilities and Utility Regulators.
   F. The Federal Government.

II. Economics of Photovoltaics on the Demand Side.
   A. The Small Portable Generator.
   B. The Private Residence.

III. Economics of Photovoltaics on the Supply Side.

IV. Distribution of Photovoltaic Devices.

V. Utilities.

VI. Market Growth and Government Policy.

VII. International Markets.

VIII. How Do Things Stand Now?

NON-RESIDENTIAL APPLICATIONS AND RUTURE TECHNOLOGY

Photovoltaic Collectors and Systems

UNIT 6. Societal Aspect of Photovoltaics.

READ: Maycock, Paul D., and Edward N. Stirewalt, Photovoltaics: Sunlight to Electricity in One Step, Brick House Publishing Co., Andover, MA, 1981, Chapter 6.

SUMMARY OF: Chapter 6.

There is every sign that our society will increasingly choose electricity as the preferred form for delivering energy to the point of use. Electricity is clean. It does not have to be hauled about. It is extraordinarily versatile in use and can be converted easily into light, heat, or motion. It can be used with great precision--in a computer, a television set, or a surgical device. Moreover, the distribution system. representing an investment of $1 trillion, is alread in place. In every sense, electrical energy is high quality energy.

In the United States, we now produce and use about 250 gigawatt-years of electricity each year. (A gigawatt-year is the amount provided by a 1,000 megawatt plant operating without interruption for one year. This would power a city of about one million persons.) Use of electricity is increasing at nearly 4 percent a year, and recent studies project that by year 2000, Americans could use from 400 to 800 gigawatt-years annually. A doubling of present use to 500 gigawatt-years would appear to be a reasonable, if not conservative, estimate of yearly use by the end of the century. Where the additional energy will come from is an open question, but it is entirely possible that photovoltaics could provide most of it.

It is important to recognize some singular aspects of massive photovoltaic deployment. For instance the cost of photovoltaics is almost entirely attributable to the creation of capital plant; it is a one-time front-loaded expense. There are no fuel costs, and maintenance costs are minimal. Most of the expense of the changeover to this new energy source would be borne by the private sector as a normal part of new construction costs, or in connection with the maintenance of existing structures. Such costs would in essence be attributable to higher quality of living. Consider: only a few decades ago, most new housing did not have central heating. Now central heating is taken for granted, and the same goes for electricity. Our economic system is able to provide these amenities and many, many more attributes of modern living. Some people earn their living providing them, and all of us enjoy the results. So it will be with photovoltaic solar energy.

The primary issues are whether technology can provide the capability at reasonable expense in terms of the human and material resources needed, and what the social and economic consequences of widespread use of photovoltaics may be.

The following outline is the remainder of Chapter 6:

I. Material and Resource Constraints in the Deployment of Photovoltaics.
II. Photovoltaics and the Environment.
III. Effect on Employment.
IV. Impact on Municipalities.
V. Photovoltaics and Net Energy.
VI. Photovoltaics and Inflation.
VII. Photovoltaics Overseas.
VIII. Other Issues.
IX. The Total Market: How Large and How Soon?

NON-RESIDENTIAL APPLICATIONS AND FUTURE TECHNOLOGY

Photovoltaic Collectors and Systems

UNIT 7. Glossary of Photovoltaic Terms.

The following glossary of terms is taken from Maycock, Paul D., and Edward N. Stirewalt, Photovoltaics: Sunlight to Electricity in One Step, Brick House Publishing Co., Andover, MA, 1981, pp. 207-215.

acceptor -- a dopant material such as boron which has fewer outer shell electrons than required in an otherwise balanced crystal structrue, providing a hole which can accept a free electron.

amorphous -- The condition of a solid in which the atoms are not arranged in an orderly pattern; not crystalline.

amper, amp -- A measure of electric current; the flow of electron. One amp is 1 coulomb (6.3×10^{1} electrons) passing in one second. One amp is produced by an electric force of 1 volt acting across a resistance of 1 ohm.

array -- See photovoltaic array.

balance of system (BOS) -- Parts of a photovoltaic system other than the array: switches, controls, meters, power conditioning equipment, supporting structure for the array, and storage components, if any. The cost of land is sometimes included when comparing total system costs with the cost of other energy sources.

band gap energy -- The amount of energy (in electron volts) required to free an outer shell electron from its orbit about the nucleus to a free state, and thus to promote it from the valence level to the conduction level.

barrier -- see cell barrier.

barrier energy -- The energy given up by an electron in penetrating the cell barrier; a measure of the electrostatic potential of the barrier.

base load -- The minimum amount of electric power which a utility must supply in a 24-hour period. Utilities typically operate their most efficient generators (usually their newest and largest) to meet base load demand. See load, peak load.

boron -- A chemical element, atomic number 5, semi-metallic in nature, used as a dopant to make p-silicon.

break-even cost -- The cost of a photovoltaic system (in dollars per kilowatt of generating capacity) at which the cost of the electricity it produces exactly equals the price of electricity from a competing source.

British termal unit (Btu) -- Amount of heat required to raise the temperature of 1 pound of water by 1 degree Fahrnheit.

cadmium -- A chemical element, atomic number 48, used in making certain types of solar cells.

capacity factor -- The output of a generating plant for a specified period of time, say a year, divided by the output if the plant had operated continuously at full rated capacity for the same period.

cathodic protection -- A method of preventing oxidation (rusting) of exposed metal structures such as bridges by imposing between the structure and the ground a small electrical voltage that opposes the flow of electrons, and is greater than the voltage that is present during oxidation.

cell barrier -- A very thin region of static electric charge along the inerface of the positive and negative layers in a photovoltaic cell. The barrier inhibits the movement of electrons from one layer to the other, so that higher energy electrons from one side diffuse preferentially through it in one direction, creating a current, and thus a voltage across the cell. Also called the depletion zone, or the cell junction.

cell junction -- The area of immediate contact between two layers (positive and negative) of a photovoltaic cell. The junction lies at the center of the cell barrier or depetion zone.

central power -- The generation of electricity in large power plants with distribution through a network of transmission lines (grid) for sale to a number of users. Opposite of distributed power.

combined collector -- A photovoltaic array which includes an optical component such as a lens or focusing mirror to direct incident sunlight onto a solar cell of smaller area.

conduction band; conduction level -- Energy level at which electrons are not bound to (orbiting) a specific ~~atomic~~ nucleus, but are free to wander among the atoms.

Conversion efficiency (cell) -- The ratio of the electric energy produced by a solar cell (under full sun conditions) to the energy from sunlight incident upon the cell.

current -- See electric current.

Czochralski process -- Method of growing a perfect crystal of large size by slowly lifting a seed crystal from a molten bath of the material under careful conditions of cooling.

deep discharge -- Discharging a battery to 20 percent or less of its full charge.

dendrite -- A slender threadlike spike of pure crystalline material, such as silicon.

depletion zone -- Same as cell barrier. The term derives from the fact that this microscopically thin region is depleted of charge carriers (free electrons and holes).

diffuse insolation -- Sunlight received indirectly as a result of scattering due to clouds, fog, haze, dust, or other substances in the atmosphere.

diffusion length -- The mean distance a charge carrier (free electron or hole) moves before recombining with another hole or elctron. Distances are short, typically several micrometers to a few hundred micrometers. Cell efficiency improves with increasing minority carrier diffusion length.

direct current (DC) -- Electric current in which electrons are flowing in one direction only. Opposite of alternating current (AC).

direct insolation -- Sunlight falling directly upon a collector. Opposite of diffuse insolation.

distributed power -- Generic term for any power supply located near the point where the power is used. Opposite of central power. See stand-alone remote site.

donor -- A dopant, such as phosphorus, which supplies an additional electron to an otherwise balanced crystal structure.

dopant -- A chemical element added in small amounts to an otherwise pure crystal to modify its electrical properties. An n-dopant introduces more electrons than are required for the perfect structure of a crystal. A p-dopant creates electron vacancies in the crystal structure.

electric circuit -- Path followed by electrons from a power source (generator or battery) through an external line, including using devices, and returning through another line to the source.

electric current -- A flow of electrons, electricity.

energy payback time -- The time required for any energy-producing system or device to produce as much useful energy as was consumed in its manufacture and construction.

EPRI -- The Electric Power Research Institute, Palo Alto, CA; the research arm of the investor-owned utilities in the United States.

fill factor -- The ratio of the maximum power a photovoltaic cell can produce to the theoretical limit if both voltage and current were simultaneously at their maxima. A key characteristic in evaluating cell performance.

flat plate (module or array) -- An arrangement of solar cells in which the cells are exposed directly to normal incident sunlight. Opposite of concentrator.

Fresnel lens -- An optical device that focuses light like a magnifying glass; concentric rings are faced at slightly different angles so that light falling on any ring is focused to the same point. Fresnel lenses are flat rather than thick in the center, and can be stamped out in a mold.

gallium -- A chemical element, atomic number 31, metallic in nature, used in making certain kinds of solar cells.

gigawatt -- One billion watts. One million kilowatts. One thousand megawatts. 10^9 watts.

grid -- Network of transmission lines, substations, distribution lines, and transformers used in central power systems.

heterojunction -- Zone of elctrical contact between two dissimilar materials. see homojunction.

hole -- A vacancy where an electron would normally be in a perfect crystalline structure.

homojunction -- The zone of contact between the n-layer and the p-layer in a single material, the two layers having been created by doping the basic crystal with other substances. See heterojunction.

insolation -- Sunlight, direct or diffuse (not to be confused with insulation).

inverter -- Device that converts DC to AC.

I-V Curve -- A graphical presentation of the current versus the voltage from a photovoltaic cell as the load is increased from the short circuit (no load) condition to the open circuit (mazimum voltage) condition. The shape of the curve characterizes cell performance.

kilowatt (KW) -- 1,000 watts.

kilowatt hour (kWh) -- 1,000 watt hours.

load -- Electric power being consumed at any given moment. The load that a utility must carry varies greatly with time of day and to some extent with season of the year. Also, in an electrical circuit, any device or appliance that is using power. See base load; peak load.

majority carrier -- Current carriers (either free electrons or holes) which are in excess in a specific layer of a semiconductor material (electrons in the n-layer, holes in the p-layer) of a cell.

marginal cost -- The cost of one additional unit within a group of like units.

megawatt (MW) -- One million watts; 1,000 kilowatts.

minority carrier -- Current carriers (either electrons or holes) which are in the minority in a specific layer of semiconductor material. It is the diffusion of minority carriers through the cell barrier that creates a voltage, and constitutes a current, in a photovoltaic device. The process becomes more efficient with increasing minority carrier diffusion length..

multiple junction cell -- A photovoltaic cell containing two or more cell barriers, each of which is optimized for a particular portion of the solar spectrum to achieve greater overall efficiency in converting sunlight into electricity. See vertical multiple junction cell and split spectrum cell.

n-silicon -- Silicon containing a minute quantity of impurity, or dopant, such as phosphorus, which causes the crystalline structure to contain more electrons than required to exactly complete the crystal structure. There is no electrical imbalance, however.

ohm -- A measure of resistance to the flow of an electric current.

open circuit voltage -- The voltage across a photovoltaic cell in sunlight when no current is flowing; the maximum possible voltage.

order of magnitude -- A factor of 10; used as a convenience in comparing large numbers.

parallel connection -- A method of interconnecting two or more electricity-producing devices, or power-using devices, such that the voltage produced, or required, is not increased, but the current is additive. Opposite of series connection.

peak load, peak demand -- The maximum load, or usage, of electrical power occurring in a given period of time, typically a day.

peak watt or watt peak -- The amount of power a photovoltaic device will produce at noon on a clear day (insolation at 1000 watts per square meter) when the cell is faced directly toward the sun.

phosphorus -- A chemical element, atomic number 15, used as a dopant in making n-silicon.

photoelectrochemical cell -- A special kind of photovoltaic cell in which the electricity produced is used immediately within the cell to produce a useful chemical produce, such as hydrogen. The product material is continuously withdrawn from the cell for direct use as a fuel or as an ingredient in making other chemicals, or it may be stored and used subsequently.

photon -- A particle of light, which acts as an indivisible unit of energy; a quantum or corpuscle of radiant energy moving with the speed of light.

photovoltaic -- Pertaining to the direct conversion of light into electricity.

photovoltaic array -- An interconnected system of photovoltaic modules that functions as a single electricity-producing unit. The modules are assembled as a discrete structure, with common support or mounting.

photovoltaic cell -- A device that converts light directly into electricity. A solar photovoltaic cell, or solar cell, is designed for use in sunlight. All photovoltaic cells produce direct current (DC).

photovoltaic collector -- A photovoltaic module or array which receives sunlight and converts it into electricity.

photovoltaic module -- A number of photovoltaic cells electrically interconnected and mounted together, usually in a common sealed unit or panel or convenient size for shipping, handling, and assembling into arrays.

photovoltaic system -- A complete set of components for converting sunlight into electricity by the photovoltaic process, including array and balance-of-system components.

photovoltaic-thermal (PV/T) system -- A photovoltaic system which, in addition to converting sunlight into electricity, collects the residual heat energy and delivers both heat and electricity in usable form. Also called total energy system. See combined collector.

polycrystalline silicon; polysilicon -- Silicon which has solidified at such a rate that many small crystals (crystallites) were formed. The atoms within a single crystal are symmetrically arrayed, whereas in crystallites they are jumbled together.

power conditioner -- The electrical equipment used to convert power from a photovoltaic array into a form suitable for subsequent use, as in supplying a household. Loosely, a collective term for inverter, transformer, voltage regulator, meters, switches, and controls.

p-silicon -- Silicon containing a minute quantity of impurity, or dopant, such as boron, which provides insufficient electrons to exactly complete the crystal structure. There is no electrical imbalance, however.

PV -- Abbreviation for photovoltaic(s).

quad (Q) -- One quadrillion (10^{15}) British thermal units. A commonly used measure of very large quantities of energy. The total consumption of all forms of energy in the United States in 1980 was about 78 quads.

recombination -- A free electron being reabsorbed into a hole.

rectifier -- A device that converts AC to DC.

remote site -- Not connected to a utility grid. See stand-alone; distributed power.

reserve capacity -- The amount of generating capacity a central power system must maintain to meet peak loads. See spinning reserve.

ribbon -- A thin sheet of crystalline or polycrystalline material, such as silicon, produced in a continuous process by withdrawal from a molten bath of the parent material.

satellite power system (SPS) -- Concept for providing large amounts of electricity for terrestrial use from one or more satellites in geosynchronous earth orbit. A very large array of solar cells on each satellite would provide electricity which would be converted to microwave energy and beamed to a receiving antenna on the ground. There it would be reconverted into electricity and distributed as any other centrally generated power, through a grid.

Schottky barrier -- A cell barrier established at the interface between a semiconductor, such as silicon, and a sheet of metal.

semiconductor -- Any material which has limited capacity for conducting an electric current. Certain semiconductors, such as silicon, gallium arsenide, and cadmium sulfide, are uniquely suited to the photovoltaic conversion process.

SERI -- The Solar Energy Research Institute at Golden (Denver), CO. Established by Congress in 1974 (Solar Energy Research, Development, and Demonstration Act) to lead the nation's solar energy research and development program.

series connection -- A method of interconnecting devices that generate or use electricity so that the voltage, but not the current, is additive one to the other. Opposite of parallel connection.

short circuit current -- The current flowing freely from a photovoltaic cell through an external circuit which has no load or resistance; the maximum current possible.

Siemens process -- A commercial method of making purified silicon.

silicon -- A chemical element, atomic number 14; semimetallic in nature; dark gray; an excellent semiconductor material. A common constituent of sand and quartz (as the oxide). Crystallizes in face-centered cubic lattice like diamond. See polycrystalline silicon.

solar cell -- A photovoltaic cell designed specifically for use in converting sunlight into electricity.

solar constant -- The strength of sunlight; 1,353 watts per square meter in space, and about 1,000 watts per square meter at sea level.

solar thermal electric -- Method of producing electricity from solar energy by using focused sunlight to heat a working fluid which in turn drives a turbogenerator.

space charge -- Same as cell barrier, depletion zone.

spinning reserve -- Utility generating capacity on line and running at low power in excess of actual load.

split spectrum cell -- A compound photovoltaic device in which sunlight is first divided into spectral regions by optical means. Each region is then directed to a different photovoltaic cell optimized for converting that portion of the spectrum into electricity. Such a device achieves significantly greater overall conversion of incident sunlight into electricity. See vertical multiple junction cell.

stand-alone -- An isolated photovoltaic system not connected to a grid; may or may not have storage, but most stand-alone applications require battery or other form of storage. See remote site.

synfuel, synthetic fuel -- Any of several fuels, usually liquid or gaseous, derived by processing such fossil sources as oil shale, tar sands, and coal.

thermal electric -- Electric energy derived from heat energy, usually by heating a working fluid which drives a turbogenerator. See solar thermal electric.

thermophotovoltaic cell -- A device that concentrates sunlight on a small heat absorber made of metal or other suitable material, heating it to a high temperature. The secondary thermal radiation re-emitted by the absorber is used as the energy source for a photovoltaic cell. The cell is chosen for maximum efficiency at the wavelength of the secondary radiation.

thin film -- A layer of semiconductor material, for example polycrystalline silicon or gallium arsenide, typically a few hundredths of an inch or less in thickness, useful in making photovoltaic cells. Use of this material bypasses the costly steps of growing single crystal ingots and sawing them into wafers. Depending on the material, thin films may be produced in different ways, such as withdrawing a ribbon from a molten bath, slowly cooling a molten sheet on a substrate, or by spray coating.

valence state; valence level energy, bound state -- Energy content of an electron in orbit about an atomic nucleus.

vertical multiple junction cell -- A compound cell made of different semiconductor materials in layers one above the other like a club sandwich. Sunlight entering the top passes through successive cell barriers, each of which converts a separate portion of the spectrum into electricity, thus achieving greater total conversion efficiency of the incident light. Also called a multiple junction cell.

volt, voltage -- A measure of the force or "push" given the electrons in an electric circuit; a measure of electric potential. One volt produces one amp of current when acting against a resistance of one ohm.

wafer -- A thin sheet of semiconductor material made by mechanically sawing it from a single crystal ingot.

watt, wattage -- A measure of electric power, or amount of work done in a unit of time. One amp of current flowing at a potential of one volt produces one watt of power.

<u>watt hour</u> (<u>Wh</u>, <u>Whr</u>) -- A quantity of electrical energy (electricity). One watt hour is consumed when one watt of power is used for a period of one hour.

<u>watt peak</u> -- Same as peak watt.

NON-RESIDENTIAL APPLICATIONS AND FUTURE TECHNOLOGY.

FUTURE APPLICATIONS

STUDENT MATERIAL

NON-RESIDENTIAL APPLICATIONS AND FUTURE TECHNOLOGY

Future Applications

UNIT 1. Cooling Systems

This UNIT 1 consists of two readings and a discussion of the concept of Solar Cooling Systems.

READ: Bilgen, E., "Solar Powered Refrigeration", Ecole Polytechnique, Genie Mecanique, Montreal, Quebec, Canada, in Solar Energy Conversion by A.E. Dixon and J.D. Leslie, Pergamon Press, 1979, Chapter 26.

SUMMARY OF: "Solar Powered Refrigeration"

Utilization of solar powered refrigeration units in cooling and food preservation is reviewed; the methods with intermittent and continous cycles are discussed. These methods include refrigeration for air-conditioning, absorption systems, and refrigeration for food preservation. The intermittent cycle of gas absorption is discussed at great length with charts and graphs of efficiency and theory for future improvement.

The article concludes that the technical feasibility of solar powered refrigeration seems to be demonstrated in several countries by many research teams using various cycles. However, there has been no systematic development of solar powered refrigeration units for ice making.

It should be noted that:

-- there are presently no solar ice makers which operate successfully; the results of successful demonstrations reported in the literature are hardly repeatable in actual conditions.

-- the cost figure and economical calculations are based on speculation.

READ: Newton, Alwin, P.E., "Solar Systems for Space Cooling", Borg-Warner, York Division (retired), and Consulting Engineer, York, PA, in Solar Energy Handbook by Kreider and Kreith, McGraw-Hill, 1981, Chapter 15.

SUMMARY OF: "Solar Systems for Space Cooling"

THe most highly developed solar-powered cooling equipment is at present the lithium bromide--water system which readily available in commercial sizes. The performance characteristics of such equipment are discussed in detail. The possible gains from dual temperature storage are also shown. Limits of performance of other cooling equipment such as ammonia absorption, Rankine drives, open absorption, and adsorption are also described in engineering detail.

Another concern of this article is the need to treat the building to be cooled and the air conditioning equipment energized by the solar system as an interacting combination. The load patterns of typical buildings are identified and the performance of auxiliary equipment such as cooling towers is shown over all normal operating conditions. The relationships between loads and varying ambient temperatures and the effect on the most effective energizing temperatures are shown in detail.

Conventional air conditioning equipment utilizes either electrical or thermal energy to drive compressors or absorption equipment to produce a cooling effect. The thermal energy obtained from the sun by means of the various types of collectors described elsewhere can be used to directly energize the absorption-type equipment, and by means of heat engines to drive compressors. The variable nature of the solar energy requires a much more complete analysis of loads and equipment characteristics than is normally made for conventional applications. This article deals with performance characteristics of commercially available air conditioning equipment and shows methods by which it can be used in solar-energized applications in the most cost effective ways. It then closes with suggestions for specifying solar cooling components and systems in such a manner as to assure that the desired equipment is obtained.

FURTHER READINGS

1. Newton, A.B., "Variable Speed Drives for Centrifugal Compressors", International Institute of Refrigeration, Proceedings of XII International Congress of Refrigeration, Washington, D.C., 1971.

2. Newton, A.B., "Optimization of Cooling Systems Energized by Solar Heat", International Institute of Refrigeration, Proceedings Joint Meeting Commissions C_2, D_1, D_2, D_3, and E_1, Melbourne, Australia, September 1976.

3. ASHRAE, Handbook of Fundamentals, American Society of Heating, Refrigerating and Air-Conditioning Engineers, New York, 1977.

4. ASHRAE, Handbook of Systems, American Society of Heating, Refrigerating and Air-Conditioning Engineers, New York, 1976.

5. ASHRAE, Computer Codes for Building Energy Analysis (ASHRAE GRP153), American Society of Heating, Refrigerating and Air-Conditioning Engineers, New York, 1975.

6. Newton, A.B., "The Meaning and Use of Consensus Standards in Rating and Certification of Solar Collectors", ASHRAE Journal, November 1978.

7. ASHRAE, Methods of Testing to Determine the Thermal Performance of Solar Collectors, American Society of Heating, Refrigerating and Air Conditioning Engineers, New York, 1977.

NON-RESIDENTIAL APPLICATIONS AND FUTURE TECHNOLOGY

Future Applications

UNIT 2. Solar Central Power Stations

READ: Caputo, Richard, "Solar Thermal-Electric Power Systems", in Solar Energy Handbook by Kreider and Kreith, McGraw-Hill, 1981, Chapter 20.

SUMMARY OF: "Solar Thermal-Electric Power Systems"

The approach to this article is similar to the comparative assessment study of several solar and conventional power systems contained in other references. This article presents several types of distributed- and central-receiver solar thermal-electric systems and performs a comparative evaluation among them and, to a limited extent, with conventional power plants. The primary factor which is considered is a projection of utility economics. But consideration is given several other factors such as a technical development difficulty, utility interface, central vs. dispersed use, and utility vs. community or private ownership. A brief review is also made of the major factors affecting social acceptance in comparison with advanced fossil, nuclear, and even solar orbital power systems. Due to the uncertainty of costs and to some extent, the performance of these various solar systems, the results are presented in two forms: the first is based on a "best judgment" estimate of all economic and technical performance factors, and the second form shows parametric data for a range of values.

NON-RESIDENTIAL APPLICATIONS AND FUTURE TECHNOLOGY

Future Applications

UNIT 3. Ocean Thermal

The largest solar collector and storage system by far is the ocean itself. The surface temperature of the oceans between the Tropic of Cancer and the Tropic of Capricorn stay at a constant of about 77°F. These warm surface waters are separated by an little as 2,000 feet from the inexhaustible source of cold water. Water typically in the ocean at 2,000 feet level is constant at 40°F. Ocean thermal energy conversion (OTEC) uses the thermal gradient as a renewable source of energy to produce electric power by utilizing the warm surface water as a heat source and the cold water from the depths as a heat sink. When a solar sea plant is installed that is large enough to span the temperature differential, heat may be extracted from the water and used to power an engine. This engine would be similar in principle to the standard heat engine, or turbine, normally used in the production of electricity.

In concept, the operation of this ocean thermal energy conversion plant would draw warm water into the plant from the surface of the ocean and pass it through an evaporator where it delivers some of the heat to boil a fluid. The resulting vapor is delivered to a turbine where it expands the low pressure and exhaust into a condensor. The turbine drives the electric generator. Cold sea water is drawn into the plant and is passed through a condensor where it picks up heat as a low pressure vapor condenses. The condensate is then pumped back to the evaporator to complete the cycle.

While ideally the major thermal resources of the oceans are available in the tropical latitudes, a relatively large quantity of thermal energy can be harnessed close to major populated areas of the United States. For example, the warm Gulf Stream is located only 15 miles off the coast of Miami, Florida. Other favorable U.S. locations for the generation of electricity include the Gulf of Mexico, Hawaii, Puerto Rico, and the Virgin Islands. Ocean thermal conversion plants located sufficiently close to shore could provide base load electricity to the land grid areas by means of underwater cable. An alternative being evaluated to the generation of electricity would be the production of an intermediate fuel such as hydrogen. This hydrogen would be processed by electrolysis. In some cases, hydrogen could be transported by pipeline to the shore. In some more remote areas, the concept of tankers would have to be utilized. Other energy intensive chemical products such as ammonia, which is synthesized from hydrogen and nitrogen from the air, are also potential products for an OTEC production system.

Futurists believe it is quite conceivable that OTEC plants might supply electricity for the offshore processing of boxite into aluminum which is a highly energy intensive process. Another use might be the open sea mariculture of shellfish using the nutrients provided by the artificial upwelling of the water from the depths. The possibilities are exciting, but it will take considerable amounts of time and money before development of work is completed and the unanswered environmental questions can be resolved.

READ: Dugger, Gordon L., Frederick E. Naef, and J. Edward Snyder III, "Ocean Thermal Energy Conversion", in Kreider and Kreith, Solar Energy Handbook, McGraw-Hill, 1981, Chapter 19.

SUMMARY OF: "Ocean Thermal Energy Conversion"

This article is a ~~key~~not article on the topic of ocean thermal conversion. ~~It~~ is detailed and covers every aspect of the topic as it relates to the energy potential.

The article concludes that by the year 2000, 1.5% to 6% of the total United States energy needs could be met with ocean thermal. The higher level might exceed the shipbuilding capacities of existing and new U.S. shipyard by the year 2000. The potential is very great; the shipyard and merchant marine jobs that could be generated, and the favorable effects on the U.S. balance of payments that could result from reduced dependence on foreign oil and liquefied gas, could be of great national benefit, if more research and experimentation with ocean thermal conversion were to take place in the 1980's.

NON-RESIDENTIAL APPLICATIONS AND FUTURE TECHNOLOGY

Future Applications

UNIT 4. Biomass Conversion

Since humans first existed as a distinct species, they have used biomass, or plant and animal material, for various energy forms including food, shelter, clothing, and fuel. Still today about two-thirds of the world's population still uses biomass for their heating and cooking. Even now late in the 20th century when fossil fuels supply many of chemical feedstocks, shelter, clothing materials, and energy requirements, we are still dependent on plants for fossil fuels or actually the remains of plant tissues which are converted to oil, coal, or natural gas over millions of years. The use of biomass as a renewable energy couse has enjoyed renewed public interest and increasingly widespread use over the last decade. The use of biomass for energy offers significant advantages over the nuclear and fossil fuel energy sources which western countries have leaned to depend upon during the past generation. Biomass is renewable, it can be produced in most regions of the world, it has negligible amounts of sulfur which results in much less air pollution than any other non-renewable source of energy, and it has no major disposal problem.

The production of biomass energy may be extremely simple or very complex. In simplicity a family may chop five cords of wood during the fall from their wood lot. This wood is to be used in a wood-burning stove during the winter months for heating one room of their home. The complex is a commercial enterprise that grows biomass on a large energy farm. The biomass is harvested, converted into methanol, mixed with gasoline, and used as a transportation fuel. Regardless of the system, they are still components of obtaining energy from biomass: 1) the growing of the biomass, 2) transporting it to the conversiton site, and 3) converting it into the form of energy which man can use.

The biomass conversion of sunlight into chemical energy is truly a simple process. Green plants have unique capability of capturing the energy of the sunlight. After capturing this energy, they convert carbon dioxide and other inorganic molecules into a chemical bond of energy. The same plants convert carbon dioxide and water into simple sugars by a series of chemical reactions called photosynthesis.. These sugars are used by the plant for: 1) maintenance, 2) growth, and 3) reproduction.

Biomass as a resource base depends upon the current and future contribution of biomass to energy supplies based on the following systems: 1) growing promising terrestrial aquatic plant species on energy farms solely for the conversion to energy, 2) collecting forced agricultural and animal residue for energy, 3) harvesting forest trees which are not suitable for lumber, paper, or other forest products. The primary resources for growing plants on terrestrial energy farms are airable land and high yielding plant species. Similarly, future aquatic energy farms would require fresh water or marine water sources and high yielding plant species. Other quality resource bases would be the forest, agricultural and animal residues, and all non-commercial existing forests. In identifying biomass resource base data, the most important issue facing the production of terrestrial energy crops is the availability of land or water resources to be allocated for such enterprises. Factors which affect the availability of land or water are:

1) the potential of land in various regions to grow energy crops, 2) competing demands for that land or water, and 3) future trends in the supply and demand of the land or water.

If you were to break down the United States into what we would consider to be an energy lot, we would find the following subdivisions. There are approximately 2,264,000,000 acres of land in the United States. Thrity-five million acres are in urban development. Twenty-six million acres are covered by recreational parks and wildlife. Two hundred, eighty-four million acres are covered by governmental installations. Seven hundred, twenty-four million acres are in cropland. Six hundred, four million acres are in grasslands. Those grasslands are typically acreages that are not used for farming and are mostly federally reserved lands. This actually leaves very few acres to be considered for energy.

Many processing options can be applied to the conversion of biomass to energy or chemicals. These processes range in the state development from labroatory scale to commercially proven processes. Conversion efficiency varies considerably with the biomass feedstock which is used. The biomass will vary in heating value, alternate analysis, approximate analysis, moisture content, and bulk density. Some of these characteristics differ only slightly in various forms of biomass, whil others vary greatly. The energy content or heating value of biomass varies with the water content, chemical composition and the density of the fibrous material.

Those biomass resources with high moisture content such as algae or animal manures, are more suitable to converting into fuels by using the bio-conversion processes of anaerobic digestion and fermentation. In the process of anaerobic digestion, micro-organisms digest biomass directly to produce methane or carbon monoxide gases. This process is currently used for the industrial and municipal waste treatment systems to reduce the volume of organic sludges prior to disposal.

The biomass fermentation process uses the micro-organisms to convert simple sugars into ethanol. The range of chemical feedstocks has evolved into a substantial chemical industry over the years. Most recently chemical hydrolysis processes have been developed to convert cellulose to other polysachharides into fermitable sugars, primarily glucose. These sugars can be then fermented to ethanol, acetone, butanol, and a range of other chemicals. Ethanol can be blended with gasoline or used directly in modification to modified internal combustion engines.

The thermal chemical processing of biomass resources includes the processes of pyrolysis, gassification, liquification, and direct combustion. A wide range of energy products can be produced, such as synthetic natural gases, methanol, fuel oil, charcoal, heat, process steam, and electricity.

In the pyrolysis process, wood is heated in the absence of air to a temperature where the wood decomposes, producing a combustible solid, liquid, and gas. In the recent past, pyrolysis of wood has been used to produce charcoal and methanol and most recently, flash-pyrolysis has been used to pyrolyze municipal refuse.

In the thermal chemical conversion gassification process both medium Btu and high Btu gases can be produced from biomass, depending on the temperature and the pressure of the reaction. Most biomass gassifiers currently under construction operate at atmospheric pressure and can yeild crude gases up to 350 Btu's or energy when partial oxidation is carried out.

Thermal chemical conversion liquification biomass can also be converted directly into oil by using sodiumcarbonate catalyst in a hydrogenation process. A process is currently under development for feeding a slurry of wood chips into a high pressur reaction vessel. Product oil can be separated from the unconventional material and water by centrifugation. Thermal chemical ~~convertion of biomass directly~~ to heat steam and electricity can be done through a direct combustion process. Thermal efficiency is limited essentially only by the heat recovery equipment downstream of the combustion chamber. For direct fired furnaces and steam boilers, thermal efficiency is as high as 85%. Generall, biomass with moisture contents below 30% can be burned directly, while those with higher moisture content may have to be pre-dried or fired with supplementary fuels. The hot combustion waste gas can be used directly for drying or preheating the biomass to be burned. The overall direct combustion efficiency of biomass used to produce electricity today is 20% to 30%, depending on the feedstock moisture content, the ash content, the plant design, and the efficiency of that plant. In comparison, efficiency is low when comparing it to that of a coal combustion plant which typically operates at 35% to 40% efficiency overall.

Thermal chemical conversion of biomass for residential use, such as, the use of wood for heating, is also very effective. One hundred, fifty years ago most all homes used wood for heating and cooking. In the early 70's, wood accounted for about 1% of all the energy used in the United States. One hundred, fifty years ago, 30 cords of wood might be burned each year to heat the typical living space of the home. Today, the same size structure, with tighter construction and more insulation, may be heated more uniformly and efficiently with far less wood. As the cost of fossil fuels and electricity have been rising, the residential use of wood for heating has also been rising.

From this brief introduction to biomass conversion, one can see that this is an upcoming innovative form of energy potential that is considered a renewable resource.

READ: "Energy from Biomass", Anne Fege, from Kreider and Kreith, Solar Energy Handbook, Chapter 25.

SUMMARY OF "Energy From Biomass":

Since humans first existed as a distinct species, they have used biomass, or plant and animal materials, for various energy forms including food, shelter, clothing, and fuel. Today, about two-thirds of the world's population still uses biomass for their heating and cooking. Even now, when fossil fuels supply many of our chemical feedstock, shelter, clothing materials, and energy requirements, we are still dependent on plants--for fossil fuels are actually the remains of plant tissues which were converted to oil, coal, and natural gas over millions of years.

Obtaining energy from biomass has enjoyed renewed public interest and an increasingly widespread use, as the prices of fossil fuels rise. The use of biomass for energy offers significant advantages over the nuclear and fossil energy souces which Western countries have depended on during the past generation. Biomass is renewable, can be produced in most regions of the world, has negligible amounts of sulfer (resulting in much less air pollution than using coal), and has no major disposal problems.

Obtaining energy from biomass may be extremely simple, or very complex. A family may chop five cords of wood each fall from their woodlot, and use it in a Franklin stove during the winter for heating one room in their home. In the future, a commercial enterprise may grow biomass on a large energy farm, harvest the material, convert it into methanol, mix it with gasoline, and sell it as a transportation fuel. Regardless of the system, there are still three components of obtaining energy from biomass: (1) growing the biomass, (2) transporting it to the conversion site, and (3) converting it into a form of energy which man can use.

This handbook chapter will describe the basis for the conversion of solar energy into chemical energy content of plants--the biomass resource base--the process for converting biomass to useful fuels, and one promising future system for increasing the amount of energy supplied by biomass. Most examples have been derived from United States experiences but the concepts and potentials for obtaining energy from biomass may be applied in many parts of the world.

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NON-RESIDENTIAL APPLICATIONS AND FUTURE TECHNOLOGY

Future Applications

UNIT 5. Wind Power

The last topic discussed in this module on Future Applications is wind energy conversion. Wind is created primarily by the unequal heating of the earch by the sun. The surface of the oceans and the lakes and the air over them remain relatively cool during the day. This is because much of the sun's insolation either is consumed in the evaporation of water or is absorbed by the large mass of water. Land surfaces, particularly dark covered terrains, heat up considerably during the day. The land then warms the overlying air which expands, becoming lighter, and rises. The cooler and heavier over the water air moves in to replace it, creating a local breeze from the water to the shore. At night, the land and the air above it cool more rapidly than the water. This cooled air then blows seaward to replace the warm air that rises from the surface of the water.

Local winds also develop on mountainsides during the day as heated air rises along the slopes, warmed by the sun. During the night the relatively cool and heavy air on the slopes flows down into the valleys producing mild breezes. Global winds, such as the trade winds, and the prevailing weterly's are also caused by differential solar heating of the earch's surface. In some locations the energy of these constant winds may be a valuable source of energy and should be tapped.

It is estimated that between 1850 and about 1935 there were more than 6 million small machines of less than one horsepower each used to pump water, generate electricity and perform milling operations throughout the rural areas of the United States. Their numbers declined drastically during the mid-30's when the government's Rural Electrification Administration introduced electrical cooperatives throughout middle rural United States, subsidizing electricity at the expense of wind power. By count today, there are about 150,000 wind machines still in operation, primarily in the western states, for pumping water for livestock on remote ranges. The common wind machine use to pump water has a 12 to 16 foot diameter rotor consisting of metal fan blades which is mounted on a horizontal shaft. A tail-vein keeps the rotor facing into the wind. The shaft is connected to gears and a cam that moves a connecting rod up and down to operate a pump at the bottom of the tower. A 12 foot diameter rotor of this type develops about 1/6 of a horsepower and 15 miles per hour wind and can pump up to 35 gallons of water a minute, to a height of about 25 feet.

Small wind machines for generating electricity normally have two or three propellor-type blades which are connected by a shaft in the gear train to a D.C. generator. The wind generators incorporate some type of energy storage system, normally a bank of batteries.

Wind machines can be classified in the terms of the orientation of their axis or rotation, relative to the direction of the wind. There seems to be three basic types of rotors, rotor configurations. <u>Horizontal axis rotors (head-on)</u>--this type of axis of rotation is parallel to the direction of the wind stream and is very typical of conventional wind pumpers. <u>Horizontal axis rotors (cross-wind)</u>--on this wind energy collector, the axis of rotation is horizontal to the surface of the earth and perpendicular to the direction of the wind stream. This type is rather uncommon and is seldom found. Vertical axis rotors--this type of wind energy collector has an axis of rotation that is perpendicular to both the surface of the earth and to the wind stream, sometimes commonly known as eggbeaters.

Along with the United States, several foreign countries now have major developmental projects to perfect new and more cost effective wind machines of various configurations and sizes. It is speculated that the smaller machines undoubtedly will experience a renaissance on the home and the farm, while large scale systems may be developed on wind farms that supply electric power for small communities or may be fed directly into the electrical grid for larger communities. The conclusion of many studies throughout the United States suggests that wind energy will soon become a viable energy option.

Solar thermal electric conversion systems collect solar radiation and convert it first to thermal energy and then to electric power. Typically, the solar heat that is transferred to the working fluid is used to generate electircity by means of a high temperature thermal dynamic cycle. At the completion of the thermal dynamic cycle, waste heat is rejected to the environment at as low a temperature as environmentally practical.

There are two types of solar thermal electric systems. Both of these systems require the same basic components: solar collection devices, conversion of solar to thermal energy, transport of thermal energy to a convertor, thermal energy to electrical conversion, desposal of use of rejected heat, and energy storage. The first, solar thermal electrical system, is called the distributed collector system. Its main characteristic is a large number of individual solar collectors, each of which collects and concentrates solar energy and converts it to thermal energy. This collected thermal energy is then transported by a fluid through a network of piping to a heat engine and a generator.

The second solar thermal electric conversion system is identified as a central receiver system. This system is characterized by a large number of mirrors called heliostats that reflect the solar energy to a single receiver mounted on a tall tower. This central receiver then collects the concentrated solar energy and converts it to thermal energy. The subsequent thermal energy is transported by a fluid to a heat engine and a generator and in turn produces electrical current. The first central receiver system is being constructed at Barstow, California by the McDonald Douglass Corporation and is expected to be on line by the year 1983.

READ: Bragg, G.M., "Wind Power", Department of Mechanical Engineering, University of Waterloo, Waterloo, Ontario, Canada, in Solar Energy Conversion by A.E. Dixon and J.D. Leslie, Pergamon Press, 1979, Chapter 47.

SUMMARY OF: "Wind Power"

This article attempts to describe the fundamentals of wind power utilization with emphasis on the information needed to decide on the basic geometry of wind power devices and to discuss the availability of wind for power generation. It also discusses briefly the economics and social acceptance of wind power devices at the present time.

Basically wind power is simply another manifestation of solar power. Wind power has a fundamental advantage over traditional solar power however in that its energy is high. The wind, being available in a mechanical form is easily converted to useful work. In particular, shaft horsepower is easily generated by a Wind Energy Conversion System (WECS). A fundamental problem with wind power, however, is that many WECS produce low RPM shaft horse power. This later disadvantage is seen to cause a number of difficulties as the article delves into the subject. The modern research on wind power is rather diffuse at present and the major problems are only slowly being identified. The field is slowly producing a comprehensive literature although good surveys of the field are few.

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SUMMARY OF: "Wind Energy Conversion Systems"

This article describes wind energy converters and their integration into power systems. Many kinds of aerogenerators are described, the most practical being analyzed in detail. In addition, the history of wind energy use, site criteria, economics, and utility interfaces are described. The article is organized in three sections--introduction, aeroturbine design, and wind-electric systems.

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