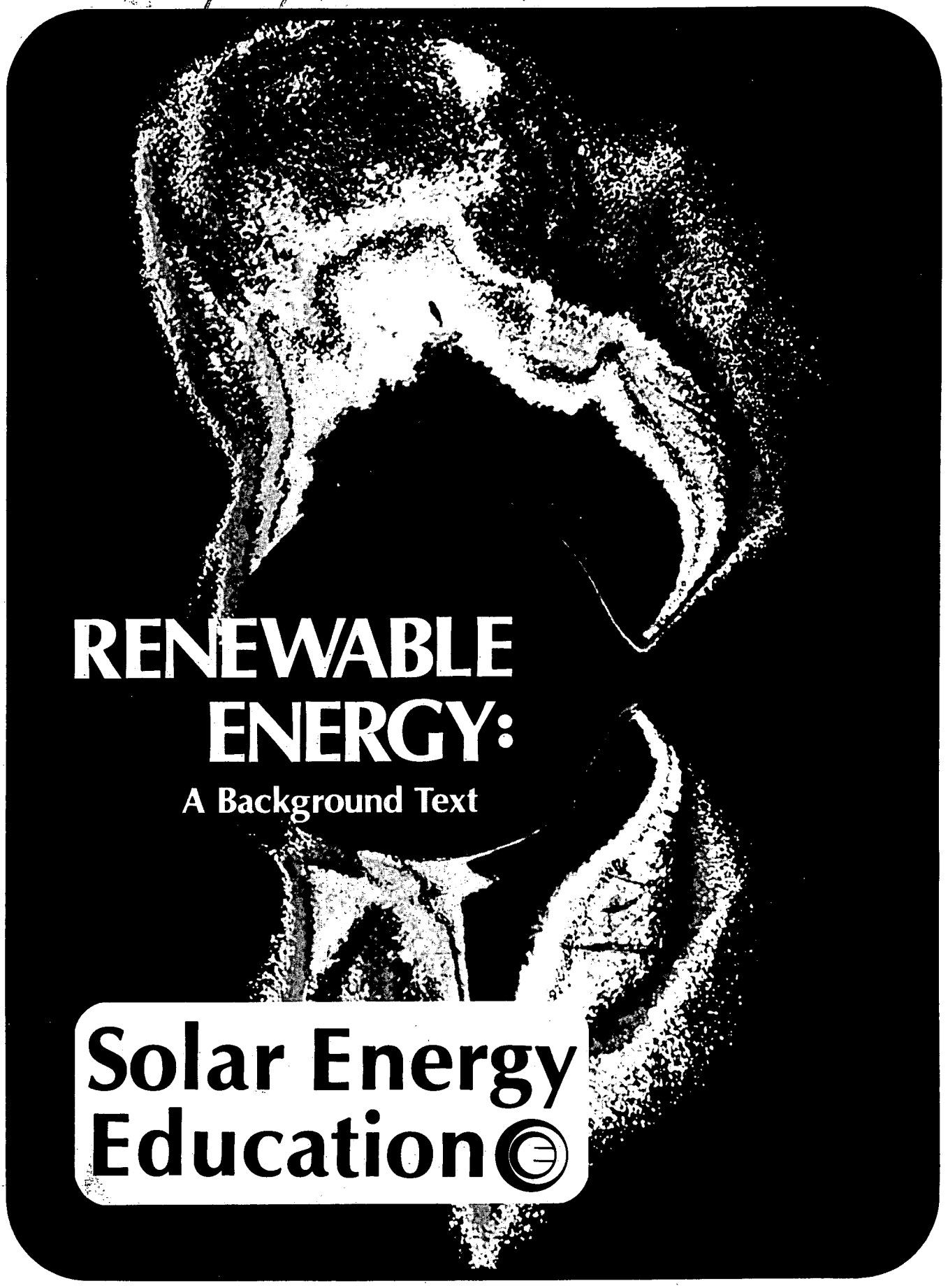
DOE/CS/34039--T9



RENEWABLE ENERGY:

A Background Text

Solar Energy Education

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Solar Energy Project Staff

Thomas A. Boehm, Director

Lesa Clark, Secretary/Layout Specialist

1977-80

Dale Westcott, Coordinator
Mary Pascucci, Administrative Assistant

1980-84

RoseAnne Fogarty, Publications Coordinator
Carolyn Graham, Training Coordinator
Karen Blaustein, Administrative Assistant
Lesa Rice, Michele Meliti, and Alexander Lerman, Clerk Typists

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

The Secondary Solar Energy Education Curriculum

was prepared for
The U.S. Department of Energy

under
Contract Number AC01-77CS 34039

by the
Solar Energy Project

in cooperation with the
New York State Education Department and
SUNY Atmospheric Sciences Research Center

Information on the Solar Curriculum may be obtained from:

Solar Energy Project
SUNY at Albany
1400 Washington Ave., P.O. Box 22425
Albany, N.Y. 12222

This document is
PUBLICLY RELEASABLE
Authorizing Official
Date: 11/14/2006

DOE/CS/34039--T9

DE85 010365

Table of Contents

Introduction 3

Acknowledgements 4

To the Teacher 6

Chapter/Activity Matrix 6

Chapter 1: **Making Friends with the Sun** 8
The sun's composition and features

Chapter 2: **A Potent Ally** 15
Solar energy, fusion, and electromagnetic spectrum

Chapter 3: **The Endless Flow** 23
Heat flow, conduction, convection, and radiation

Chapter 4: **A Solar Collector in Space** 30
Earth compared to a solar collector

Chapter 5: **The Tented Sky** 38
The atmosphere and its effect on insolation

Chapter 6: **A Complex Equilibrium** 44
Earth-atmosphere heat balance

Chapter 7: **Making It Move** 50
The role of winds and currents in distributing solar energy

Chapter 8: **A Home Issue** 60
Local factors affecting insolation

Chapter 9: **Metering the Sun** 69
Measuring insolation at a given site

Chapter 10: **Understanding the Solar Solution** 75
A broad discussion of solar applications

Chapter 11: **Living Space That's Solar** 81
Passive solar design

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Chapter 12: Saving What You Gain 93
Conservation: siting, insulation, windbreaks, etc.

Chapter 13: Collecting Sunshine Actively 104
Basics of solar collectors: materials and design

Chapter 14: Moving and Storing Sunshine 113
Transport and storage in active solar systems

Chapter 15: Your Own Solar System 120
Active solar efficiency and costs

Chapter 16: Concentrated Sunshine 130
Focussing collectors and central receivers

Chapter 17: Volts from the Sun 136
Photovoltaics and the solar power satellite

Chapter 18: Wind Power 143
Windmills and wind turbine generators

Chapter 19: Water Power 151
Water wheels and turbines

Chapter 20: Biomass: Green Energy 159
Food, compost, wood, methane, ethanol, thermochemical products

Chapter 21: Power from the Earth and Ocean 170
Ocean thermal, tidal, and geothermal energy

Chapter 22: Solar Support 178
Legal and financial implications of solar energy

Glossary of Renewable Energy Terms 184

References 201

Metric Conversion Table & Energy Units 208

Introduction

Familiarity breeds . . . indifference. From worshipping the sun as a deity of fearful power and divine beauty, humans have come to regard it proprietarily as "that lucky ol' sun" who "has nothin' to do." Once feared by the Arabs as a mighty hammer poised above the "Sun's Anvil," once placated by the Aztecs with human sacrifice, once regarded as the true ancestor of Japan's emperor, the sun is now merely an incidental fixture in the universe. We simulate it with sunlamps, and then circumvent it with sunscreening lotion; we work in windowless cubicles all day under artificial lights; we air-condition our summer and then run to Florida in the winter.

What a distance we have come, in our wondering adulation of our own accomplishments, from early humans who turned to the sun as life-giver and comforter. For the ancient Stonehenge, erected as a circular solar temple and observatory, we now have cities erected on a gridiron plan, where each structure's sunlight is blocked out by the next. Turning our backs on the sun's warmth, we glory in artificial "climate control" in our "planned environments."

Perhaps our experiments with fusion, and our probes of the moon and planets, have made us feel that the sun too is within our grasp. Yet try as we may, we cannot do for ourselves what the sun does, and has done, and will do for us for billions of years to come. Maybe in these anxious times we will again learn to mark its coming and going, and to measure our lives by its rising and setting.

That is why this book was written: to promote a new awareness of the sun. The book's sections cover topics ranging from the sun's composition and impact on the earth as a whole, to specific systems for using solar energy, and finally to speculations about legal, economic, and social effects of solar development. Originally designed for teachers, this material has been expanded to be useful to students and other members of the public who want information about solar energy.

The goal of this book, then, is to make you more aware of how the sun pervades your life, and to show you systems for tapping this great fountain of life that showers us with radiant energy every day.

Acknowledgements

Project Advisors

Edward Lalor
Douglas Reynolds
John Favitta
John Higham
Volker Mohnen
Ronald Stewart

Project Instructors

Eric Allen
Bruce Bailey
Lillian Clinard
Raymond Falconer
Philip Falconer
James Healey
John Kwasnoski
Donald McClenahan
James MacKenzie
Thomas Norton

Subject Area Advisors

The New York State Education Department's

Bureau of Curriculum Development
Bureau of Art, Music and Humanities Education
Bureau of Home Economics and Industrial Arts
Bureau of Science Education, and
Bureau of Social Studies Education

Project Artists

Lesa Clark
David Colon
Frederick Haber
Sybil Schwartzbach

Project Typists

Ellen Altschuler
Margaret Hasselwander

Special thanks to

The Word Processing Center, Office of General Education, State Education Department

Text Reviewers

Conrad Gohlinghorst
Gordon Guffner
Marilyn J. Herman
William J. Murray
Rick Nelson
Robert Romer
Pamela Shaw
Wallace Tyner
Joel A. Weiss

Text Writers

RoseAnne Fogarty
Robert Hennig

Activity Reviewers

Thomas Atkinson
Jane Cappiello
Gerald Cerne
Mary Crum
David Heacock
Larry Kershnar
Richard King
William Legg
David Marhafer
Karen O'Neil
Stephen Rumsey
Al Sholtes
Edward Snyder
Michael Trinkala
Bruce Tulloch
David Wentworth

Activity Writers

Science

Joseph Accongio
George Andrzejewski
Francis Angellotti
Kathryn Balmer
Barbara Baxter
Thomas Berle
John Blakes
Bryan Buchanan
Carol Burkhart
Dorothy Buzzell
Carleton Campbell, Jr.
Peter Cardamone
Alan Cederstrom
William Cheesman
Joseph Clancy
Constantine Constant
Vincent Corsall
Harry Cressman
Mary Crum
Ellen Curry, R.D.C.
John Dadeo
Rosario Dalia
Arnold Dansky
Donald Dashnaw
Robert Dayton
Edmund DeJulio
Federick Deussing
Robert Eustace
Kevin Fager
Mark Flamendorf
Monroe Fremed
Joanne Gallagher
Robert Gleason
Howard Gohl
Clyde Goodrich
Carolyn Graham
Elwood Hacker
Thomas Hoak
Robert Hennig
William Kellerhals
James Kennedy
James Klausen
Wesley Knapp
Joan Kosinski
Gary Kosowsky
Daniel Kujawinski
Barbara Lehman
Michelle Mazon
James Mazza
William Metzler
John McGrath
Theodore Mullen
David Nilsen
Thomas O'Day
Karen O'Neil
Damon Ormsby
Ronald Quinn
Marion Rappl, R.S.M.
Richard Rohrlack
Nicholas Romano
Arthur Rondeau
Mary Agnes Scanlon
Alfred Scarpinato
Alfred Schutte
Robert Shimony
Paul Siebold
Anita Silver
Reuben Silver
David Smith
Richard Springer
Arthur Stark
Leonard Star
Charles Sumprer
Michael Terpin
Deyo Trowbridge
Bruce Tulloch
Raymond Vittucci
Robert White
Steven Whitman
Kenneth Zacharias

Industrial Arts

John Ditton
Robert Dodds
David Gierke
Charles Halsey
Robert Muller

Home Economics

Betty Buell
Nancy Marks
Jeanne Ortiz
Marilyn Stevens
Cindy Theiss

Social Studies/Humanities

Elizabeth Ann Asaro, R.D.C.
Henry Boehning
Joanne Chambers
Sylvia Corwin
Charles Frahme
John Graham
Carol Houck
Rebecca Kelch Johnson
Rolfe Lawson
William Murphy

The Project also wishes to acknowledge the assistance of

The Northeast Solar Energy Center,
The Mid-American Solar Energy Complex,
The Southern Solar Energy Center and
The Western Solar Utilization Network

and of the more than 1,000 teachers nationwide who field-tested the Secondary Solar Energy Education Curriculum

To the Teacher

This text developed organically, started by one teacher, finished by another, and reviewed and critiqued by many. The book was intended to provide teachers with a quick inservice course on solar energy and related renewable energy sources. It was written then, for you the teacher.

Accompanying the text are five booklets of activities for junior and senior high science students. No attempt was made to coordinate chapters of the book with specific activities from the Renewable Energy Activities booklets. In fact, each activity is a small text in itself, containing whatever information is needed to teach it.

Activities

Chapters	Junior High/Middle School Science										General Science					
	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6
1			●													
2			●													
3			●		●											
4	●	●					●									
5					●			●								
6					●			●		●						
7									●					●		
8				●							●	●				
9				●							●	●				
10													●		●	●
11	●					●			●		●	●			●	●
12	●							●			●		●		●	●
13	●	●			●	●	●			●					●	●
14		●		●					●						●	●
15		●			●										●	●
16		●													●	●
17															●	●
18														●	●	●
19															●	●
20															●	●
21															●	●
22											●	●			●	●

However, it seemed to us that parts of the text might come in handy for use in conjunction with certain activities. Especially for advanced students, there are information and diagrams here that you might like to use in your teaching. Hence the matrix on these pages.

The Solar Energy Project staff would like you to note that

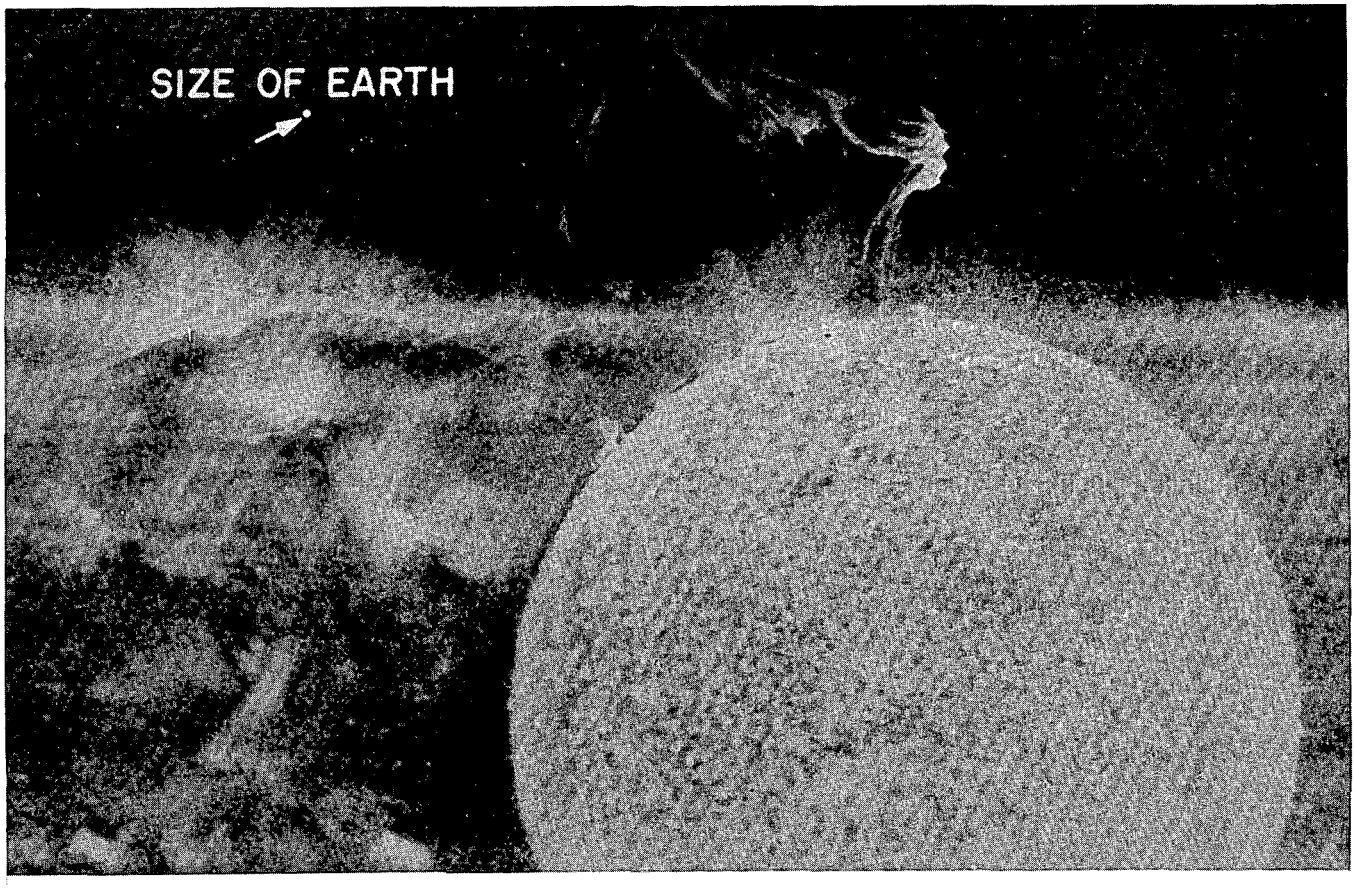
THERE ARE NO RESTRICTIONS ON THE DUPLICATION OF THIS TEXT OR OF THE ACTIVITY BOOKLETS, AS LONG AS DUPLICATION OF THE MATERIAL IS DONE BY TEACHERS, FOR NONPROFIT, CLASSROOM USE.

Activities

Chapters	Earth Science						Biology					Chemistry/Physics				
	1	2	3	4	5	6	1	2	3	4	5	1	2	3	4	5
1	●														●	
2	●											●			●	
3	●	●												●	●	
4		●												●		
5		●														
6		●				●										
7																
8			●		●										●	
9			●	●	●										●	
10											●				●	
11				●												
12																
13						●	●					●	●	●		
14												●	●	●		●
15												●	●	●		
16																
17					●											
18																
19																
20							●	●	●	●	●					
21																
22				●												

Chapter 1

Making Friends with the Sun



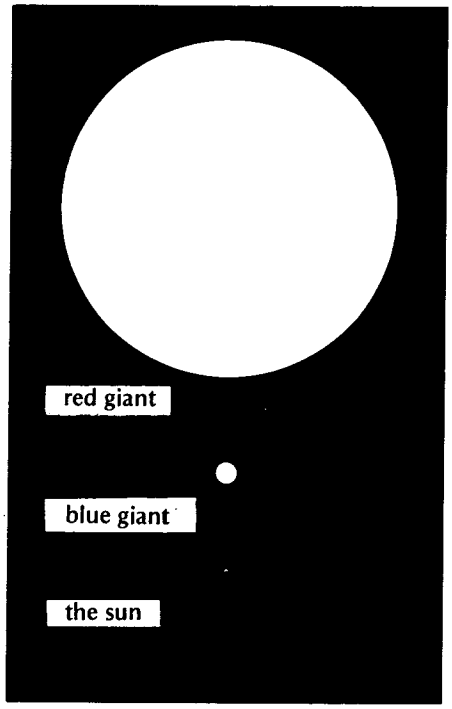
National Aeronautics and Space Administration

There are many things that we don't understand. Some things elude our gaze because they are too far away or too tiny, like the outer reaches of the universe, or the structure of the atom. Other things are too abstract for us to visualize, like the concept of infinity.

There are still other things, though, that many of us don't understand because we've never given them much thought. They're "too close," too familiar. The sun is like that. Because it is the nearest star, scientists have found out quite a lot about it, but since most of us don't give it much attention it remains a stranger.

Suppose you hear, for example, that the sun is 1,382,000 kilometers (864,000 miles) in diameter, that its volume is 1,300,000 times that of the earth, and that its mass is equal to that of 330,000 earths. Those are just numbers; they have no real impact. But if you look at a picture like the one on the facing page, you start to understand what those numbers mean. When you then realize that the sun is just an average star, you gain more respect for some of those little, twinkling specks out there that are actually gigantic suns in their own distant solar systems.

Here is a basic profile of our sun.



The scale of the sun to other stars

Sun Data

Description:	"Yellow dwarf" (midway between the hottest blue stars and the coolest red ones)
Size:	Medium (tiny compared to red super giants like Antares)
Age:	Middle-aged (about 5 billion years old with probably 5 billion to go)
Composition:	Hydrogen and helium gas (and small amounts of oxygen, carbon and other elements)
Personality:	Hot and under extreme pressure. At its core the sun is probably about 16,000,000°C and has a pressure 100 billion times greater than our atmospheric pressure.
Distinguishing features:	Sunspots, prominences, and flares
Power output:	Enormous! (3.86×10^{26} W)

C (Celsius): the temperature scale in which 0° is the freezing point and 100° the boiling point of water; (formerly called "centigrade").

power: the rate at which work is performed, measured as units of energy per unit of time. (See glossary.)

W (watt): a unit of power; one joule/second. (See glossary.)

These data may generate a few questions in your mind. For example:

Is the sun the same from its center to its surface?

Not at all. It consists of several layers, each one having a different temperature and density and performing different processes. Of course, the boundaries between these layers aren't sharply defined, as they seem to be in the diagram. Remember that the sun is gas, so its layers blur into one another.

Let's start at the core. With temperatures of 16,000,000°C and pressures 100 billion times greater than our atmospheric pressure, the core is an enormous thermonuclear reactor, always working full blast and releasing tremendous energy. (The meaning of that thermonuclear reaction will be explained in Chapter 2.)

energy: the ability to do work or make things move; it exists in many forms (electrical, kinetic or motion, gravitational, light, atomic, chemical, heat) and can be converted from one to another. (See glossary.)

Around the core is the radiation zone. In this region energy is being transmitted from the core by radiation, at the speed of light, like heat from a fire.

radiation, the process of: the emission of waves or particles that transmit energy through space or through some medium. (See glossary.)

speed of light: the speed at which radiation travels in a vacuum; almost 300,000 kilometers/second.

Next comes the convective zone, a very turbulent, unstable area. Much less dense than the inner areas, this zone transmits energy by convection of masses of gas, each atom of gas carrying energy toward the surface.

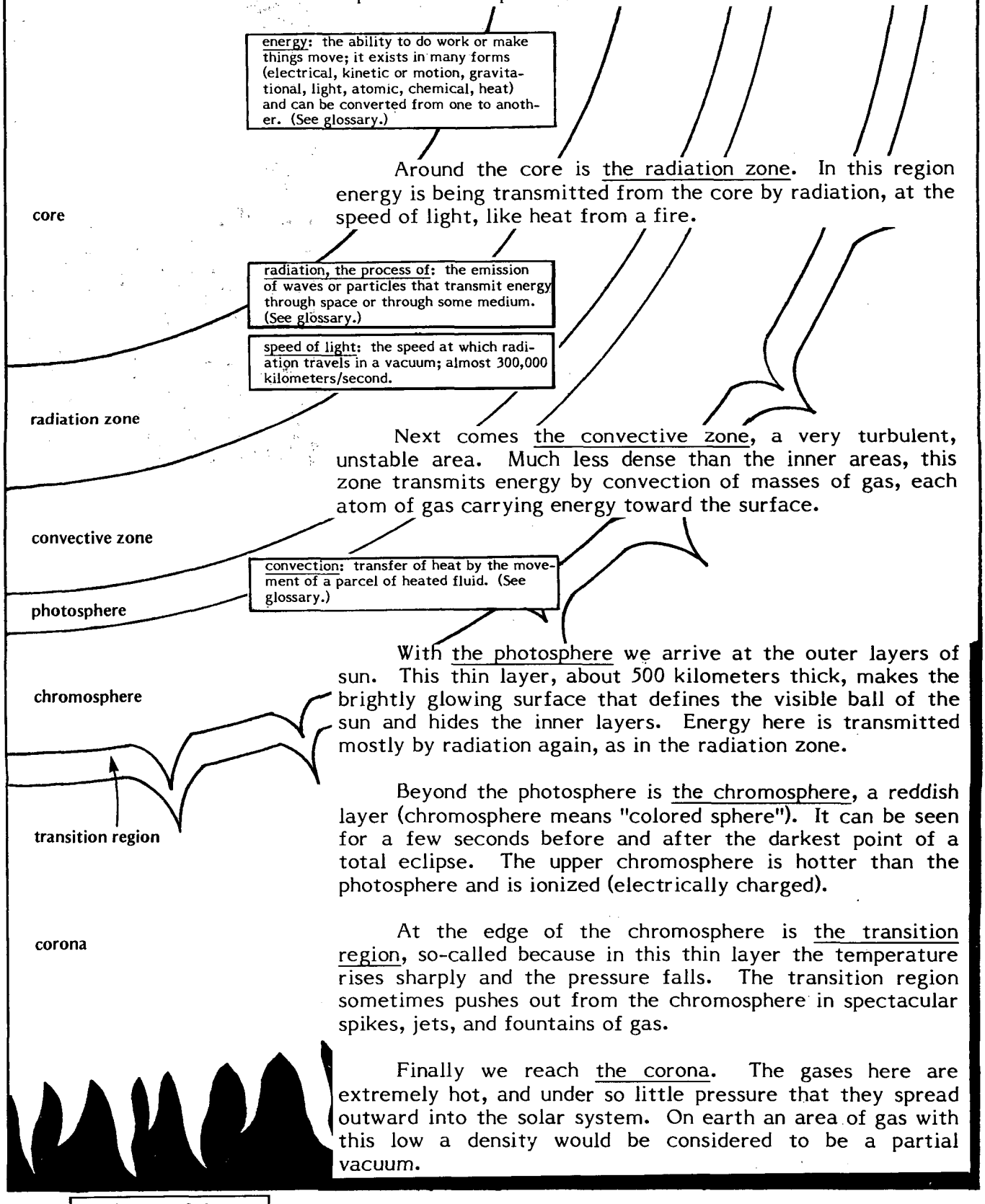
convection: transfer of heat by the movement of a parcel of heated fluid. (See glossary.)

With the photosphere we arrive at the outer layers of sun. This thin layer, about 500 kilometers thick, makes the brightly glowing surface that defines the visible ball of the sun and hides the inner layers. Energy here is transmitted mostly by radiation again, as in the radiation zone.

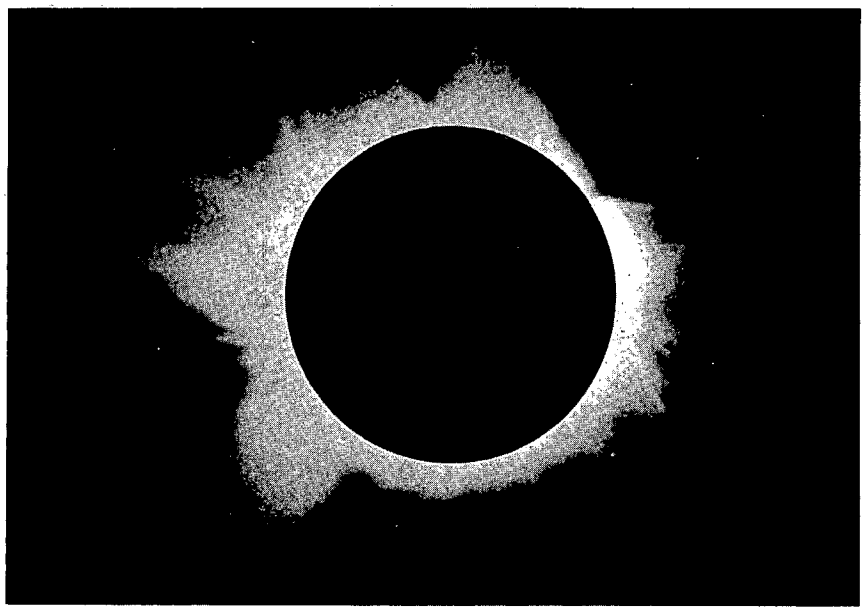
Beyond the photosphere is the chromosphere, a reddish layer (chromosphere means "colored sphere"). It can be seen for a few seconds before and after the darkest point of a total eclipse. The upper chromosphere is hotter than the photosphere and is ionized (electrically charged).

At the edge of the chromosphere is the transition region, so-called because in this thin layer the temperature rises sharply and the pressure falls. The transition region sometimes pushes out from the chromosphere in spectacular spikes, jets, and fountains of gas.

Finally we reach the corona. The gases here are extremely hot, and under so little pressure that they spread outward into the solar system. On earth an area of gas with this low a density would be considered to be a partial vacuum.



The layers of the sun



National Aeronautics and Space Administration

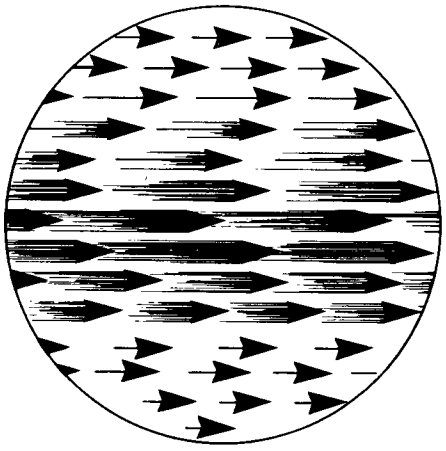
A total solar eclipse reveals the structure of the sun's corona.

The hairs of the corona, streaming out from the sun, can be seen during a total eclipse. Some scientists say that, in a sense, the whole solar system is within the sun's corona and that the "solar wind" (high speed particles that reach out beyond the planets) is simply an extension of the corona.

Is the sun stationary?

No, it rotates on an axis just as the earth does. But because it is gaseous, it doesn't all rotate uniformly like a solid. The part of the sun around its equator makes one rotation in about 25 earth days. The parts near the poles are slower, taking about 33 days to make a complete rotation.

The sun also apparently revolves around the center of our galaxy in a circular orbit, at about 200 miles per second, carrying its solar system with it. It takes about 200 million years for one circular trip.



The differential rotation of the sun

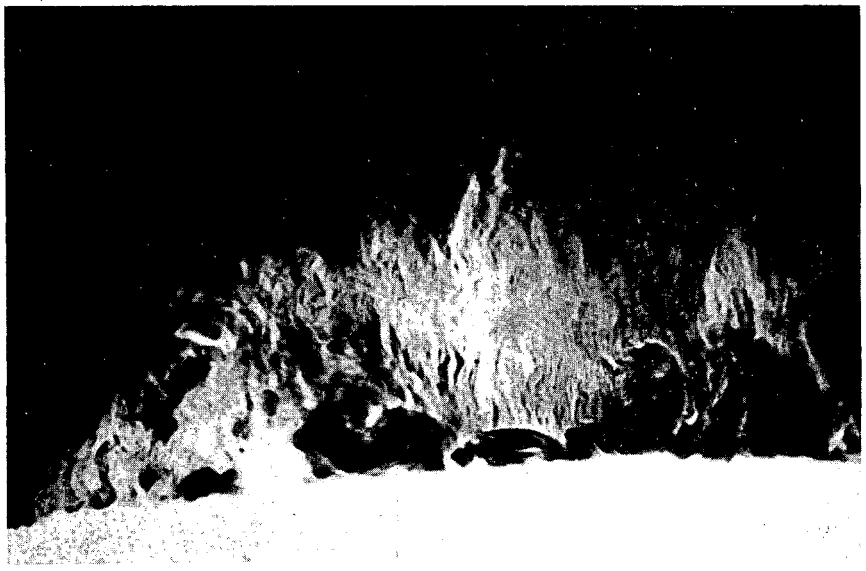
What are all the solar phenomena we hear of: sunspots, flares, prominences, plages, filaments, etc?

All of these are related to active regions on the sun's surface, mostly grouped near the equator.

Sunspots are dark regions on the photosphere. They often appear in pairs, with dark lines or filaments spreading from their centers, and they seem to follow an 11-year cycle. Scientists now think that they are areas of very high magnetism which block heated gas rising to the surface.

Plages (French for "beaches") are especially bright, high-energy areas in the chromosphere that cover sunspot areas in the photosphere. A flare is a sudden brightening in an area of plages. It indicates a sudden burst of radiation and energized particles that can sometimes be felt in the earth's upper atmosphere and magnetic field.

Prominences are perhaps the most beautiful solar phenomena. They are streamers of cooler chromosphere, extending into the hotter corona. Some look like eruptions, some like flames, and some like great fountains of matter that leap and then fall back into the chromosphere.



Sacramento Peak Observatory

Rising from chromosphere is a delicate, non-erupting prominence, about 50,000 kilometers high.

Observing the Sun Safely

Never look directly at the sun; it may damage your eyes. The lens of the eye can focus the sun as a concentrated spot on the retina, causing a burn. Pain is not always felt, and the injury may not be noticed until there are problems with sight.

Don't look at the sun through a lens or an optical device made with lenses. Concentrated rays can burn the eye. Project the sun, instead, through the optical instrument onto a screen of cardboard or paper.

Avoid using semi-opaque or translucent lenses or filters at the end of an optical system. They have been known to crack suddenly, not leaving time to close the eye and prevent eye damage.

Avoid homemade filters such as overdeveloped negatives, smoked glass, etc., for sun viewing. They are not always effective in filtering wavelengths of light that can injure the eye. Instead, project the sun through a pinhole onto a screen mounted in a box.

Sunlight reflected from mirrors, polished metal, foil, etc., can be as dangerous as the direct rays of the sun. Be sure when using mirrors to follow the same precautions given for direct sunlight.

Turn optical instruments away from the sun after a short time. Heat can build up in the instrument and affect the future performance of the lenses.

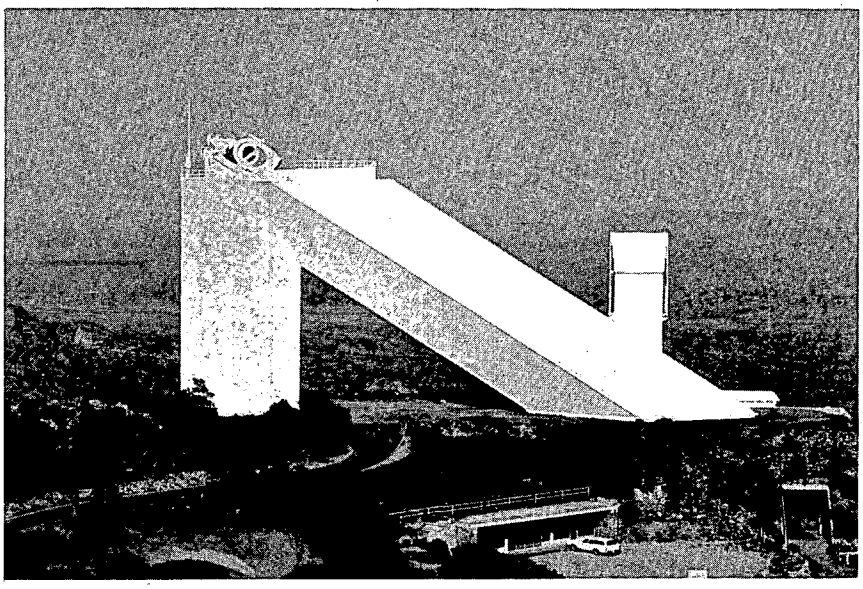
Don't leave lenses, mirrors or optical instruments "set up" where the sunlight passing through might be observed by a passerby, or might melt or ignite something.

What is the earth's place in this picture?

The earth's path around the sun is an ellipse, so it is sometimes slightly closer to the sun than at other times. But the average distance is 149,600,000 kilometers (93 million miles). No realistic picture of that can be shown because if the earth and the sun were shown at the same scale and size as on the first page of this chapter, they would have to be 15 meters apart (almost 50 feet).

How do we know so much about the sun?

We don't. That is to say, there are some things that we know through observations and calculations, some things that we can hypothesize based on knowledge of gases, energy, and motion, and some things about which we are still seeking answers. Although we can't bore into the sun's core, we can do what one scientist called "intellectual boring."



Kitt Peak National Observatory

The McMath solar telescope in Arizona is one of the more recent instruments designed to probe the sun.

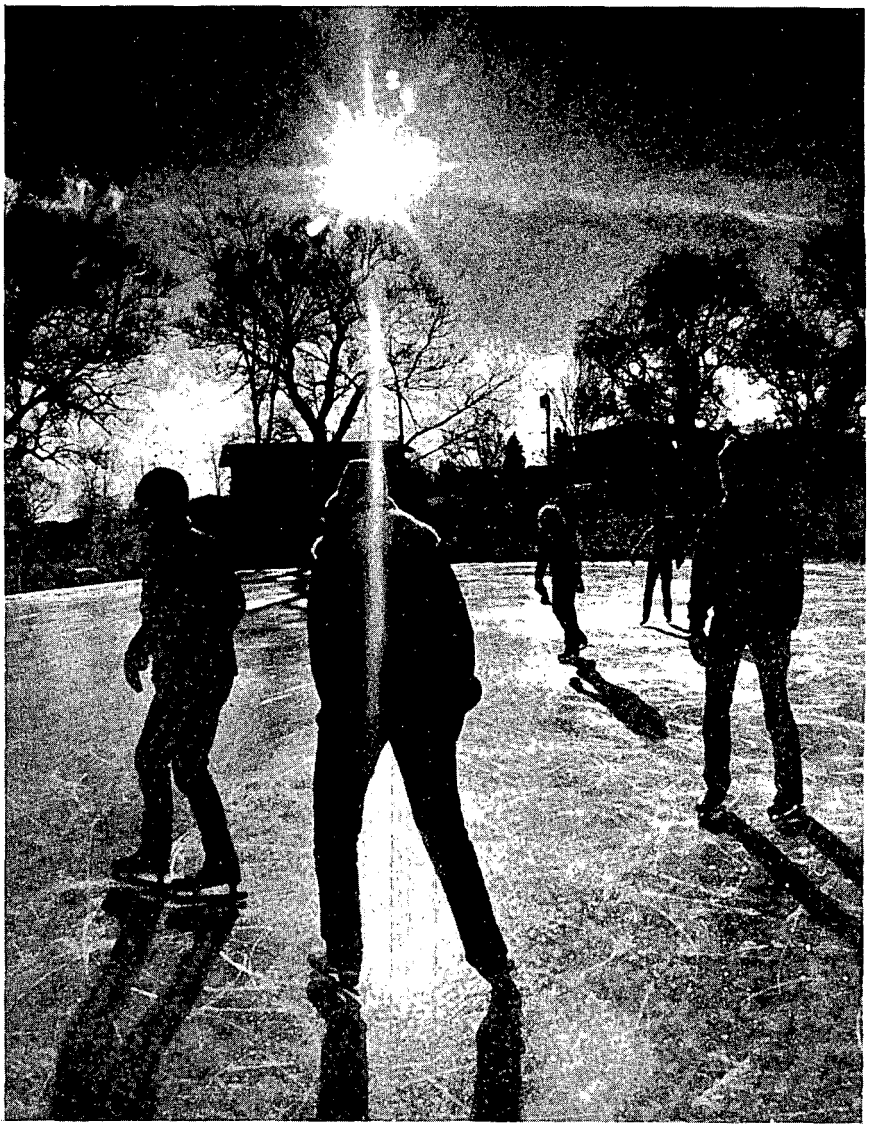
How long does it take the sun's energy to reach the earth?

This question isn't as simple as it sounds. We know that the sun's energy travels at the "speed of light." We also know that the speed of light is extremely high -- 300,000 kilometers/second -- but that means energy traveling in a straight, unobstructed line. The sun's core is so dense that when energy is produced it doesn't get far before it is absorbed by the densely packed particles. It is then emitted and absorbed again, over and over, with some energy loss in the process. It actually takes thousands, perhaps millions, of years for energy to get from the core to the surface of the sun. Then, as light energy, it covers the much greater distance to earth in about 8 minutes!

How much of the sun's energy reaches the earth?

Less than one billionth touches our tiny sphere. Still, that's about 1.7×10^{17} watts, far more power than all the earth's power plants generate. In fact, in a couple of weeks the sun gives us as much heat and light as we could produce by burning all the oil, coal, and wood on earth.

It would be dishonest to imply that all of that energy is right out there for us to trap and use. Much of it is reflected into space, is absorbed by the atmosphere, or cannot be used for various reasons. The rest of this book, however, will tell you what realistic potential the sun's energy has for us.



Reprinted with permission of The Knickerbocker News, Albany, NY

Chapter 2

A Potent Ally

If we perceive carelessly, we may describe incorrectly. How many times have you heard the sun called "a fiery ball" or "a hot ball of burning gases"? Descriptions like these show a misunderstanding of either the sun or burning or both, because the sun is not "burning" in the normal sense at all.

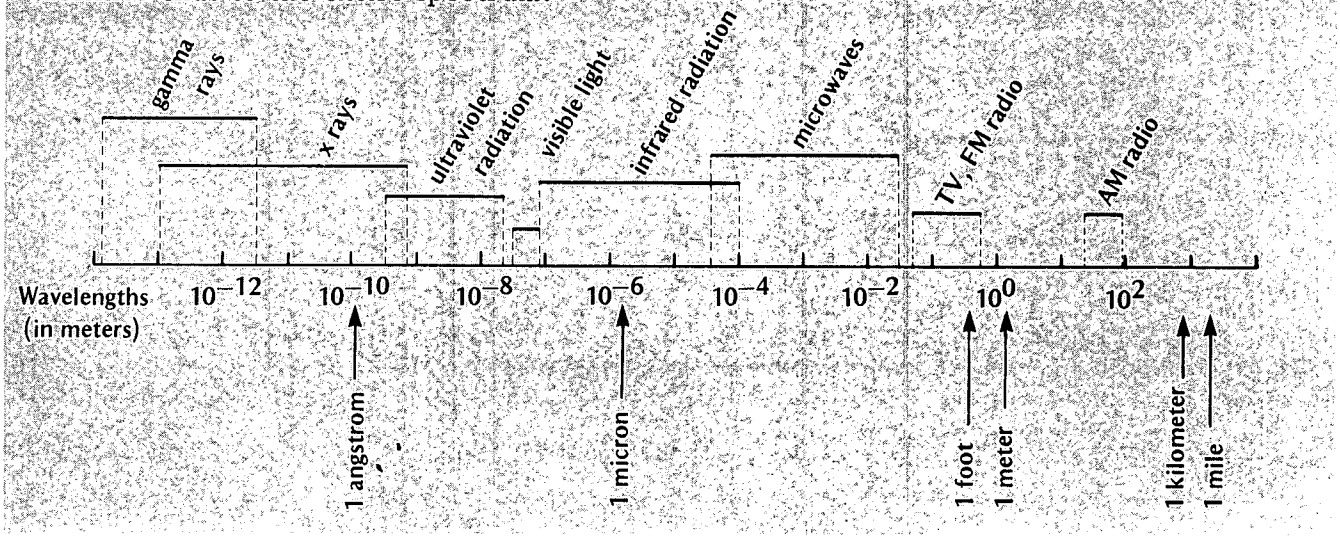
Burning is a chemical reaction; that is, it rearranges the groupings of atoms without destroying or changing the atoms. When a thing burns it combines with an oxidizing agent, giving off heat and light in the process. Elements aren't created or destroyed in burning, simply rearranged. It is this kind of reaction that gives us the energy we get from coal, oil, and gas.

Solar energy, by contrast, comes from the continuous nuclear reactions going on at the core of the sun. A nuclear reaction involves the basic structure of the atoms themselves. One element is actually transformed into another, and tremendous amounts of energy are released in the form of electromagnetic radiation. The difference between burning and this kind of reaction, then, is literally the difference between a candle and the sun.

electromagnetic radiation: the broad range of radiant energy in the universe.

The Electromagnetic Spectrum

One of the most exciting events in intellectual history occurred in the 19th century when Maxwell deduced from his theory of electricity and magnetism the possibility of electromagnetic waves, travelling at a speed of 3×10^8 meters/sec. This figure was already known as the speed of light; it was immediately realized that visible light is just one particular type of electromagnetic wave, with a particular range of wavelengths to which our eyes happen to be sensitive. The diagram shows the approximate wavelengths of several types of radiation. It should be noted that all of these waves are fundamentally similar to one another and that there are no sharp boundaries between the regions and no definite ends to the entire spectrum.



Atoms and Atomic Particles

atom: the smallest unit of a chemical element.

electric charge: a property of matter that causes electric phenomena. Like charges repel one another; unlike charges attract.

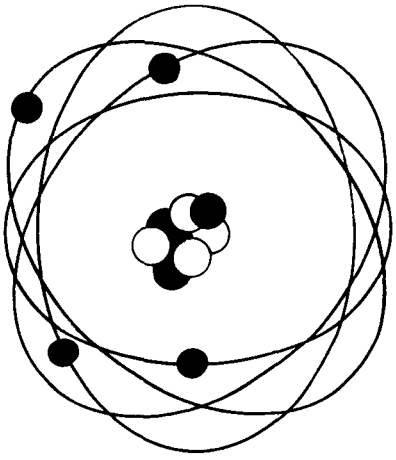
To move toward an understanding of solar energy, you have to understand nuclear reactions. First, let's review some of the parts of the atom that have been identified and named.

Proton— a particle in the nucleus (center) of the atom having positive electric charge. The number of protons in the nucleus gives an element its atomic number.

Neutron— an uncharged particle in the nucleus. The combined number of neutrons and protons in the nucleus gives an element its mass number.

Nucleon— general name for particles in the nucleus (protons and neutrons).

Electron— a particle outside the nucleus with a negative electric charge and a much smaller mass than protons and neutrons.



The atom's structure is something like this: the protons and neutrons are grouped in a very small, tightly packed, dense center, the nucleus. The protons and neutrons, although constantly moving, arrange themselves in a stable structure. The electrons are much lighter and move in an organized pattern sometimes visualized as orbits at great distance from the nucleus. This means that most of the area occupied by an atom is actually empty space.

Nuclear Notation

There is a convenient shorthand way of describing nuclei. A nucleus made of two protons and one neutron has an electrical charge of 2 units (from the protons). When this nucleus is in a complete atom, it will have two electrons outside the nucleus; it is thus an "isotope" of the element helium (He), the second element in the periodic table. Its "atomic number" (or "proton number") is 2; on the other hand, its mass is determined by the total number of nucleons (protons and neutrons), and so its "mass number" (or "nucleon number") is 3. This information is summarized in the symbol:

mass number
or
nucleon number

$$He^{3}_{2}$$

atomic number
or
proton number

Another example is the nucleus which has 38 protons (an isotope of strontium (Sr), element 38 in the periodic table) and 52 neutrons, a total of 90 nucleons:

$$Sr^{90}_{38}$$

Often the atomic number is omitted; we may simply write Sr^{90}, and say "strontium-ninety".

If there were only electrical forces acting on nuclei, then protons would repel one another (because like charges repel). But in addition to electrical force there is a strong, attractive nuclear force which acts at very short distances. It operates between any two protons, two neutrons, or a proton and a neutron.

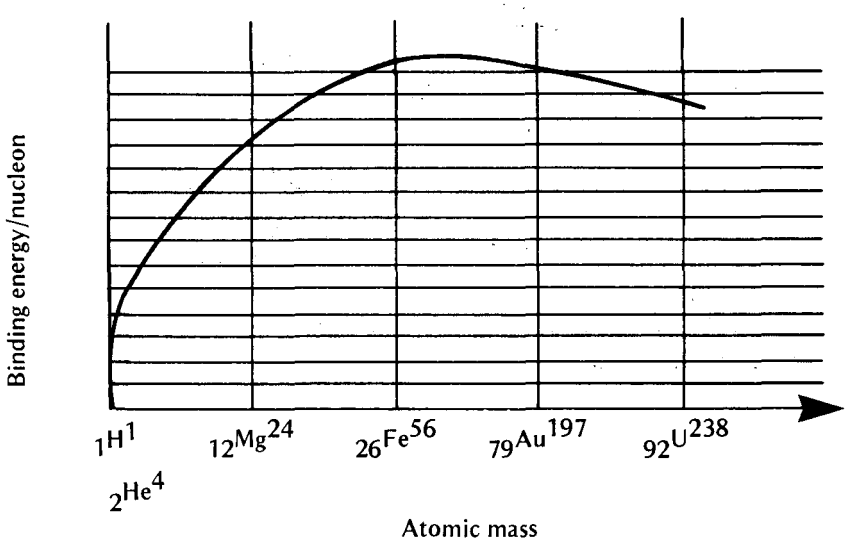
When protons and neutrons are joining and make a nucleus, they attract one another by this nuclear force. Thus, when united, they have less energy than when separated. To break them apart we would have to supply energy. This quantity of energy, called binding energy, is the key to nuclear reactions. It is the energy that is released when two unstable atoms combine and form one more stable atom (or one unstable atom splits and forms two more stable ones).

But what makes an atom stable or unstable?

Big nuclei tend to have larger binding energies than small nuclei, just because they are bigger. If you divide the total amount of binding energy of a nucleus by the number of nucleons, you get the binding energy per nucleon. This number is important because it gives us information about the relative stability of various nuclei.

If you study the chart below you will notice that as the mass number increases, so does the binding energy per nucleon - up to a point. But past that point the nuclei become so large that even though they have a high level of binding energy, their binding energy per nucleon decreases. This means they are less stable. Generally speaking, the "medium" elements like iron have the most binding energy per nucleon and therefore the most stability. So it would seem that the transformations of unstable elements to more stable elements will move from the ends of the scale toward the middle.

That is exactly what nuclear reactions are all about.



Nuclear Reactions: Three Kinds

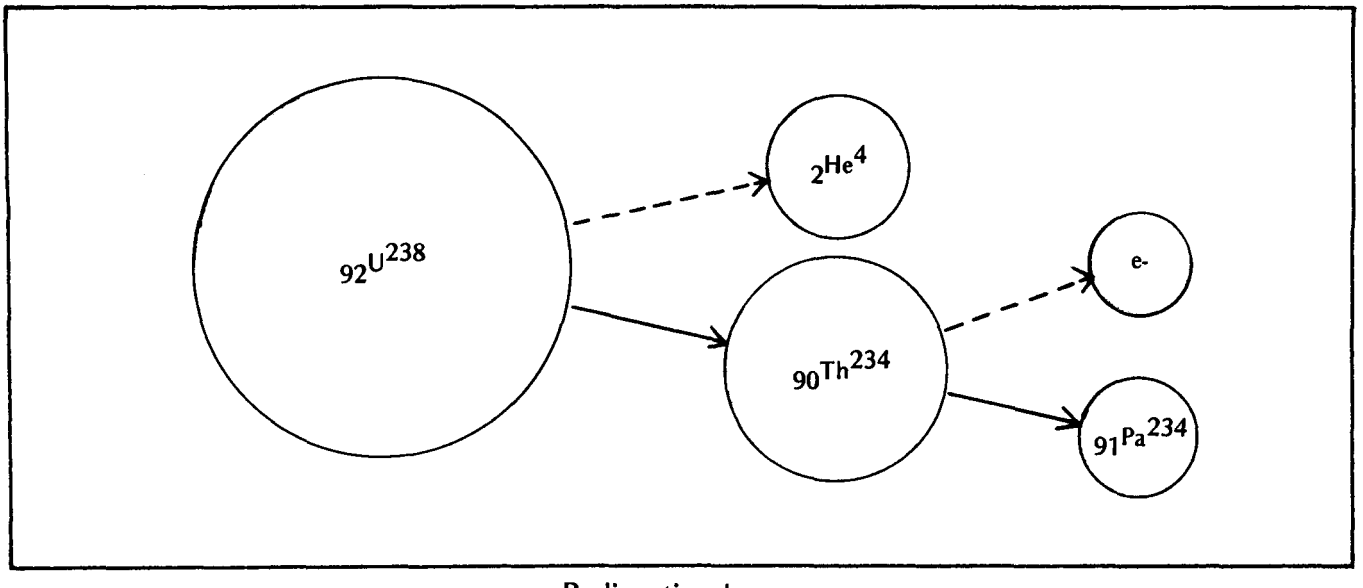
There are several kinds of nuclear reactions, some natural and some humanly induced.

Radioactive Decay

An element that tends to react by itself is called "radioactive." There are a number of radioactive elements found in nature; uranium and thorium are two examples.

These are "heavy elements," that is, they have a large number of neutrons and protons in their nuclei.

Because protons have the same charge, they repel each other. Where there has been sufficient binding energy it will overcome this repulsion. But with a very large, heavy nucleus with many protons, the binding energy may not be strong enough to overcome the electrical repulsion. Elements with this type of nucleus are unstable and tend to break down, giving off either alpha particles (composed of 2 protons and 2 neutrons) or beta particles (electrons). As a result of this "radioactive decay," the original element becomes a new element. The new element may have a lower atomic number and mass number, due to lost protons and neutrons, or the same mass number but a higher atomic number, due to the loss of electrons which then increases the positive charge of the nuclei. Eventually, through a series of these transmutations, the unstable, radioactive atoms become stable, nonradioactive atoms with lower atomic numbers and mass numbers.



Radioactive decay

Alpha and Beta Decay

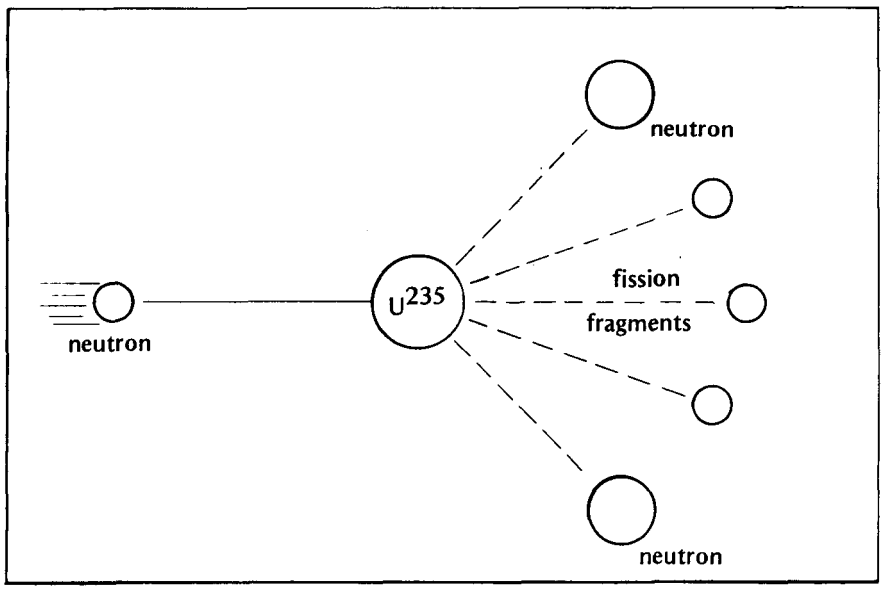
Some radioactive nuclei decay by giving off alpha particles; others ($_{38}Sr^{90}$ for example) emit energetic particles with negative electrical charge, christened beta particles. Beta particles were found to be indistinguishable from the electrons which normally surround the nucleus to make a complete atom. Because beta particles (electrons) are sometimes emitted from the nucleus, it was first thought that electrons existed inside the nucleus. This seemed reasonable, but later turned out to be inconsistent with other evidence. Instead, we now think of a beta particle as being created at the moment of emission.

What happens, in effect, is that a neutron (with no charge) inside the nucleus turns into a proton (+ charge), creating and ejecting a beta particle (- charge). Also created at the same time is a neutrino, an almost undetectable particle with no electrical charge and a mass much smaller even than that of an electron. Consider the beta decay of $_{38}Sr^{90}$ as an illustration. When a neutron turns into a proton, the total number of nucleons (the mass number) remains 90, but the proton number (or atomic number) increases to 39. Thus the new nucleus is an isotope of element number 39, yttrium, and so the process can be summarized by:

$$_{38}Sr^{90} \longrightarrow {}_{39}Y^{90} + \text{beta particle} + \text{neutrino emitted}$$

Fission

The reaction that we call nuclear fission has been brought about during this century through human effort. In a sense, it is a spectacularly speeded-up form of radioactive decay, using particularly unstable elements like one form of uranium, U^{235}. When an atom of uranium 235 is struck by a low-energy neutron from another atom it splits into two smaller nuclei and gives off other neutrons which strike and split other atoms, setting up a chain reaction. The splitting causes movement and collision, generating a tremendous amount of heat from a relatively small amount of matter.



To keep the chain reaction going after the original neutron strikes the original atom you have to have a large enough amount of the radioactive material to make continued collisions probable. This amount is called the "critical mass." When two smaller masses of radioactive material are brought together to make a large enough mass, you have the basis for a nuclear explosion.

Fusion

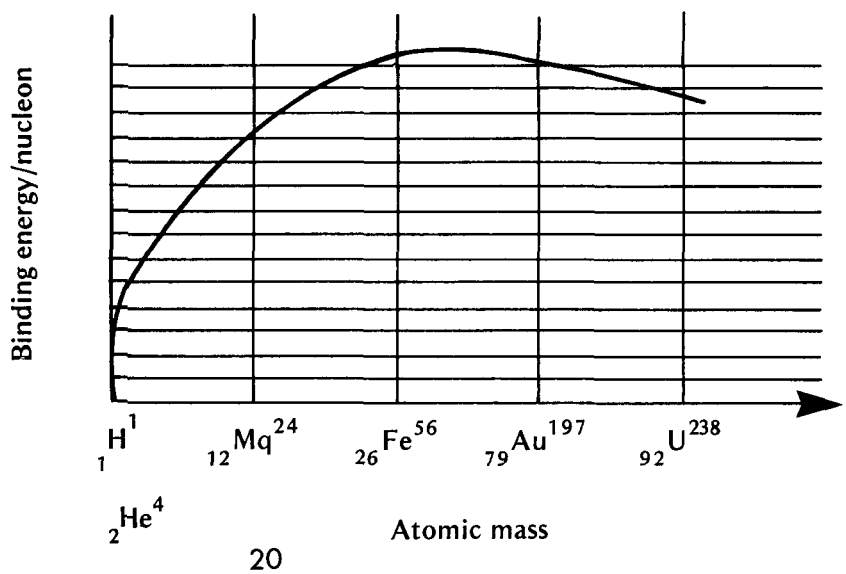
The fusion reaction is something that humans are now struggling to produce, control, and channel. The explosive energy of this reaction is the same type of energy that fuels the sun.

A fusion reaction requires tremendous heat, and thus is called a thermonuclear reaction. One way that humans so far have been able to generate the heat necessary to start the reaction is through a preliminary fission reaction which is then followed by a fusion reaction; we know it as the hydrogen bomb. Lasers are also being used to trigger fusion reactions. But the sun has the necessary temperature in its core all the time, as well as the necessary element -- hydrogen.

laser: a device that emits a very intense, directed beam of light of just one wavelength.

Scientists now think that the sun and its planets formed out of a large, contracting cloud of gas and dust. As the sun grew, its gravitational force increased, it attracted more matter, and grew even larger. Finally the temperature and pressure of the core reached the levels necessary to sustain a fusion reaction.

Hydrogen, the sun's most abundant element, is the basis of the reaction. If you look again at the binding energy chart, you'll notice that hydrogen, with a mass number of one, has no binding energy. Helium, with a mass number of four, has a considerable amount of binding energy. If hydrogen atoms could be fused to form helium atoms, tremendous energy could be released. The sun, with its core temperature of 16,000,000°C, does precisely that.



In a series of reactions, hydrogen ($_1H^1$) becomes deuterium, a hydrogen isotope ($_1H^2$), then a helium isotope ($_2He^3$), and then helium ($_2He^4$). Through this series of reactions, four hydrogen atoms, each with an atomic mass of 1.008 atomic mass units, have become one helium atom with an atomic mass of 4.003 amu's. The remaining 0.029 mass units, about 0.7% of the mass involved in the reaction, converts to energy.

atomic mass unit (amu): a standard mass unit equal to 1/12 of the mass of a carbon atom.

$4 \times 1.008 = 4.032$
$4.032 - 4.003 = 0.029$ = mass converted to energy

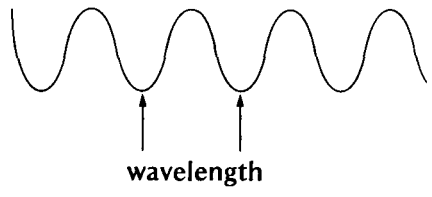
This fusion of hydrogen is the source of the sun's energy. Every second the sun converts millions of tons of hydrogen in its core to helium. Its power output is roughly 4×10^{26} watts.

Solar Radiation

The energy released by the fusion of hydrogen in the sun's core begins as gamma rays, which are very high-energy, high frequency, short wavelength radiation. The rule for the energy content of radiation is: the shorter the wavelength and the higher its frequency, the higher the energy content. ($E = hf$ where E is energy, h is Planck's constant, and f is frequency.)

frequency: the number of cycles completed by a periodic wave in a unit of time.

wavelength: the distance between two similar, consecutive points on a periodic wave.



Since all electromagnetic radiation travels at the speed of light, we'd expect the gamma radiation from the core to get to the surface almost instantaneously. You'll recall from Chapter 1, however, that this can't happen because of the density of the sun's core, which causes the gamma rays to collide with closely packed particles. In the process of being absorbed and reradiated by these particles, the wavelength and frequency of the radiation changes. By the time it reaches the sun's surface, about 9% is still high-energy radiation (ultraviolet or x-ray), 41% is visible light, and 50% is of longer wavelengths than visible light (infrared).

In spite of this loss of intensity, the energy released from the sun's surface is still tremendous. A square centimeter of the sun's surface, a space about this size ( ), gives off as much visible light as thousands of light bulbs.

The Earth's Solar Constant

The sun's energy radiates outward in all directions, and the earth occupies only a minute fraction of that surrounding space. So only a small proportion of the sun's total radiation sweeps across this tiny target. At the top of our atmosphere, a surface perpendicular to the sun's rays receives 1.94 calories per square centimeter per minute. (A calorie per square centimeter is called a langley.)

calorie: a metric unit of heat energy. (See glossary.)

This value, 1.94 langleys/minute, is the "solar constant," our solar constant, which only varies about 3% from the mean with changes in solar activity and in the earth's orbit. Using different units, we can say that at the surface of our atmosphere facing the sun we are receiving energy at a rate of about 1350 watts per square meter.

Our earth-atmosphere system tempers this tremendous power, collects it, transforms it, circulates it, and stores it. As our attention shifts from the sun to the earth, we will see how solar energy reaches us, in what quantities and what forms, and how much of the energy we have been struggling to obtain is already ours for the taking.

Brookhaven National Laboratory

Chapter 3

The Endless Flow

National Solar Heating and Cooling Information Center

For understanding to grow it must be well grounded. To see how the sun can serve us, we have to understand the link between the sun's energy and heat. When we understand how the sun's energy produces thermal energy on earth and how that thermal energy is transferred and transformed, we can comprehend and even improve on the many methods humans have devised for harnessing solar energy.

Thermal Energy, Heat, and Temperature

Thermal energy, heat, and temperature are not the same thing. Thermal energy is the kinetic energy of the constantly moving particles making up a substance. The

more thermal energy, the faster the movement. Temperature is simply a measure of the average kinetic energy of all those particles in the substance. What we call "heat" is thermal energy flowing from areas of higher temperature to areas of lower temperature.

Heat Flow

To speak simply, heat flow is "bumping." Fast-moving particles of the higher-temperature substance "bump" the slower-moving particles of the adjacent lower-temperature substance and get them moving faster. When we look at heat flow this way it's easy to understand why the amount of thermal energy transferred depends on more than just temperature. It also depends on the mass of the substance giving up the energy. A dense mass of many fast-moving particles would naturally do more bumping than just a few widely-spaced fast-moving particles.

Heat capacities in cal/g—°C

Water	1.0
Ice	0.5
Aluminum	0.22
Gold	0.031
Brick	0.2
Cement	0.16
Rocks	0.2
Wood	0.3 - 0.6
Glass	0.1 - 0.2
Air	0.17

Remember that we said in Chapter 1 that the gases of the sun's corona are very thin, reaching out from the sun into space. So the corona, although extremely "hot," would not heat an object placed within it. This is because although the particles of gas in the corona are very active and high in thermal energy, they are so widely spaced as to be what we would call a vacuum. Obviously the corona has very low mass and, therefore, little ability to transfer heat.

specific heat capacity: the quantity of heat required to raise a unit mass of a material one degree in temperature (will hereafter be referred to as "heat capacity").

The other factor affecting heat flow is the different "specific heat capacities" of different substances. It takes 1 calorie (heat) to raise the temperature of 1 gram of water 1 degree Celsius. But with glass, only 0.1 to 0.2 calories is required to produce the same increase in temperature. And a gram of gold will rise 1°C in temperature with the application of only 0.03 calories.

calorie: a metric unit of heat energy. (See glossary.)

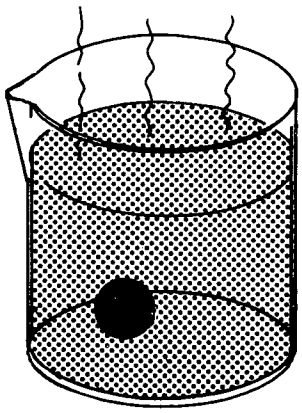
Calculating Heat Flow

Δ(delta): a symbol for "difference." ΔT means "temperature change," or "temperature difference."

We've seen that the quantity of heat which can flow between two substances depends on the starting temperature, the mass, and the heat capacity of each substance. The equation for this is:

Quantity of Heat = Heat capacity x Mass x Temperature change

$$Q = C \times M \times \Delta T$$



Suppose we took 100 grams of water with an initial temperature of 50°C and dropped a cold glass marble into it. We then found that, a minute later, the temperature of the water had dropped two degrees to 48°C. What would that show us about the quantity of heat that had flowed from the water to the marble?

$$Q = 1\ cal/g^{o}C \times 100g \times 2^{o}C = 200\ cal.$$

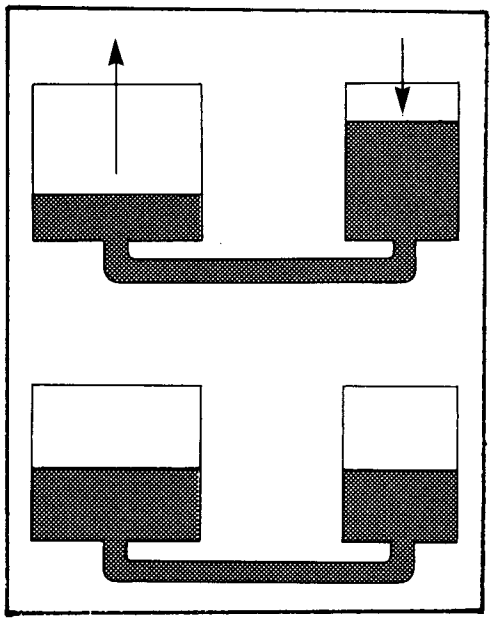
We would know, that in a minute's time, 200 calories of heat had flowed from the water to the marble. If we know that the marble weighs 50 grams and, being glass, has a heat capacity of 0.2, how much has its temperature changed in a minute?

$$\Delta T = Q/Cm$$

$$\Delta T = \frac{200\ cal.}{0.2\ cal/g^{o}C \times 50g} = \frac{200}{10} = 20^{o}C$$

So the marble's temperature has gone up $20^{o}C$.

Flow and Equilibrium



Suppose that after a transfer of 200 calories, both the water and the marble are now at $48^{o}C$. The rise in temperature of the marble will now stop. Why?

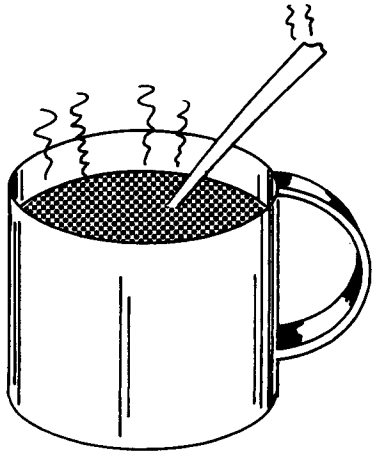
Think of the bumping particles. The fast-moving particles of the hot water bump the slow-moving particles of the cold marble. The marble's particles speed up, and the water's particles slow down from the bumping. Eventually all the particles reach the same speed (indicated by equal temperature). Then neither can have any further effect on the other, since they're at the same temperature, with equal bumping in either direction.

Another way of saying it is that heat acts like a fluid seeking its level. It will flow from one substance to another until equilibrium is reached, and then the flow will stop. So the marble can't become hotter than the substance that is heating it.

The Transmission of Thermal Energy

Now that we have some understanding of the theory of heat and heat flow it's time to examine the ways in nature that thermal energy gets around. They are all quite familiar to us, and only need review.

Conduction



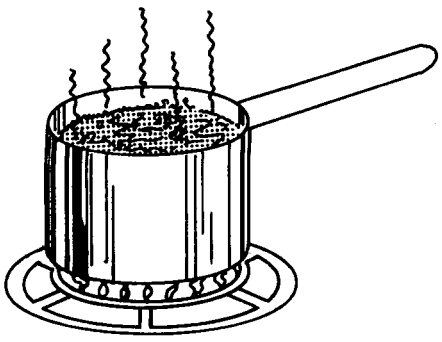
Conduction is the direct transfer of kinetic energy from atom to atom or molecule to molecule. This is the "bumping" described in our discussion of heat flow. Some substances are better conductors than others. If you want to cool your cup of coffee, leave a silver spoon in it for a couple of minutes. Silver is a good conductor; heat will travel up the handle and be transferred to the surrounding air.

In conduction, the amount of heat transferred depends on the nature of the substance doing the conducting, the size of the areas that are in contact, the temperature difference between the two, and the length of time they are in contact. But in every case, fast-moving particles are transmitting energy to slower-moving particles, and heat is flowing from areas of more heat to areas of less heat.

Convection

Heat has other ways of getting around besides the direct flow of conduction, and one of those ways is convection. Convection is the movement of a mass of heated fluid (liquid or gas). It gets its start from conduction.

When an amount of a fluid comes into contact with a higher-temperature surface, it takes on heat directly, by conduction, and its particles become more active. But because it is a fluid, those faster-moving particles collide more, spread out neighboring particles more in these collisions, and thus expand into a larger area. This makes the heated fluid less dense than the rest. If the heated, less dense fluid is below the rest of the fluid, gravity will cause the more dense fluid to flow downward, displacing the less dense fluid and buoying it upward.



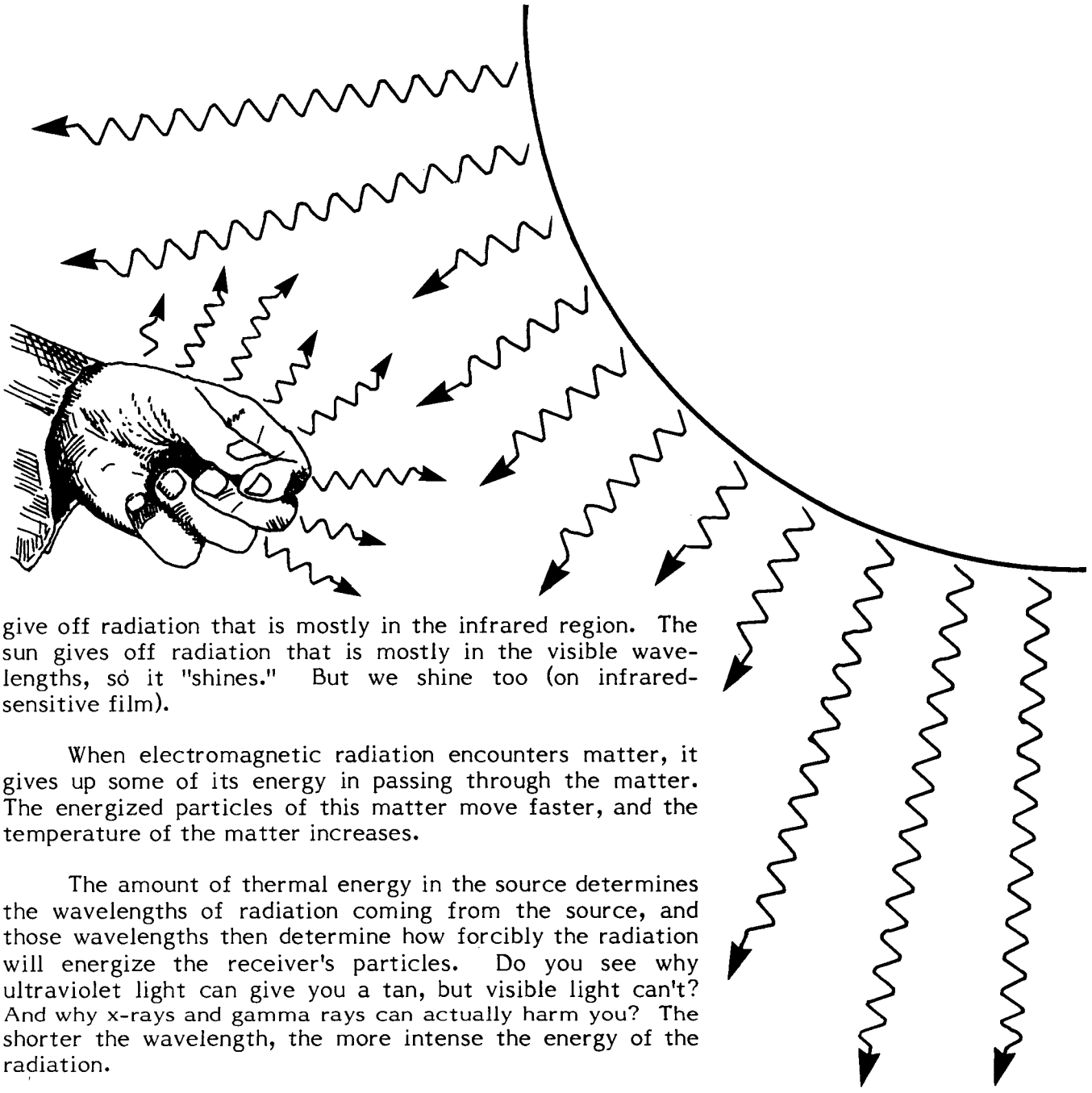
You set up this pattern of circulation when you heat a pot of water on the stove. Because convection takes place, all the water in the pot will eventually heat up, either by contact with the bottom of the pot or with the heated water around it.

Radiation

Radiation is still another way that heat moves. In this case, the energy from a heated substance is transmitted to another substance without the two ever coming into physical contact, and without any conduction or convection between them. Though this may sound mysterious it's a very familiar phenomenon, because it is the method by which the sun's energy reaches earth across millions of kilometers of empty space.

Radiation involves the transfer of energy by electromagnetic waves. These waves have electric and magnetic properties, and do not need a material medium for transmission. Chapter 2 discussed this radiation, which has a variety of wavelengths, from long radio waves to extremely short gamma rays. Regardless of wavelength, all electromagnetic radiation travels at the same speed; 300,000 kilometers/second, the "speed of light." One unit used to measure radiation wavelengths is the micrometer. A micrometer is 10^{-6} meters, and its symbol is μm.

Any object that has thermal energy gives off some electromagnetic radiation. What level of radiation it gives off depends on how much thermal energy it has. You and I



give off radiation that is mostly in the infrared region. The sun gives off radiation that is mostly in the visible wavelengths, so it "shines." But we shine too (on infrared-sensitive film).

When electromagnetic radiation encounters matter, it gives up some of its energy in passing through the matter. The energized particles of this matter move faster, and the temperature of the matter increases.

The amount of thermal energy in the source determines the wavelengths of radiation coming from the source, and those wavelengths then determine how forcibly the radiation will energize the receiver's particles. Do you see why ultraviolet light can give you a tan, but visible light can't? And why x-rays and gamma rays can actually harm you? The shorter the wavelength, the more intense the energy of the radiation.

Celsius and Kelvin Temperature Scales

The Kelvin or "absolute" temperature scale, with temperatures indicated in ^{o}K (degrees Kelvin) is similar to the Celsius scale, with the important difference that 0°K is at -273°C. There are excellent reasons for regarding this temperature as a truly absolute zero, a lower limit on the temperatures achievable by any means whatever. Theoretically, at 0°K, molecular motion would stop and a body would contain no heat energy at all. Moreover, the laws of radiation, describing the way in which the radiation emitted by hot bodies varies with temperature, take on a particularly simple form when temperatures are expressed on the Kelvin scale.

Any temperature on the Celsius scale can be converted to the Kelvin scale simply by adding 273; thus, for instance, a comfortable room temperature is about 20°C or 293°K.

The Laws of Radiation

If we're going to understand solar energy, we have to understand the laws that govern radiation. There are three that are important. Actually, these are idealized laws that only apply to "black bodies," hypothetical materials that are perfect absorbers and emitters of radiation. Still, these laws give good approximations for real situations involving real objects.

First is the Stefan-Boltzmann Law: Total energy emitted by a source is directly proportional to the fourth power of the absolute (Kelvin) temperature of the source.

Kelvin (absolute temperature scale): a temperature scale in which 0° (approximately -273°C) represents the point at which the internal energy of objects is at a minimum (absolute zero).

$\propto$: a symbol meaning "varies as," used to indicate proportions.

$$E \propto T^4 \ (^{\circ}K)$$

Obviously, as temperature increases, the energy emitted increases rapidly.

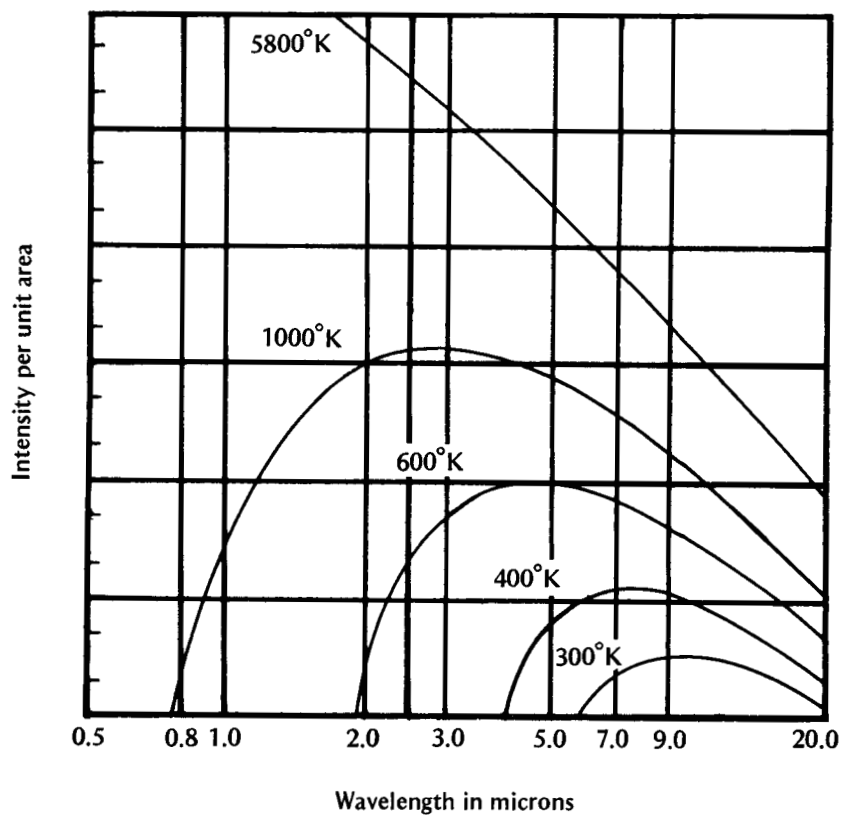
The second is a law we will discuss in greater detail in Chapter 4. It is Wien's Law, which states that: The wavelength of radiation emitted most intensely by a body is inversely proportional to the absolute temperature of the body.

λ (lambda): a symbol meaning "wavelength."

$$\lambda max \propto 1/T \ (^{\circ}K)$$

We can see from this that the higher the temperature of a body is, the shorter will be the wavelength of the radiation it emits most intensely.

The third law is the most general radiation law, Planck's Law, (which actually includes both of the previous two laws.) Since it is rather complex, it is best shown on a graph like the one below, which shows the amount and the



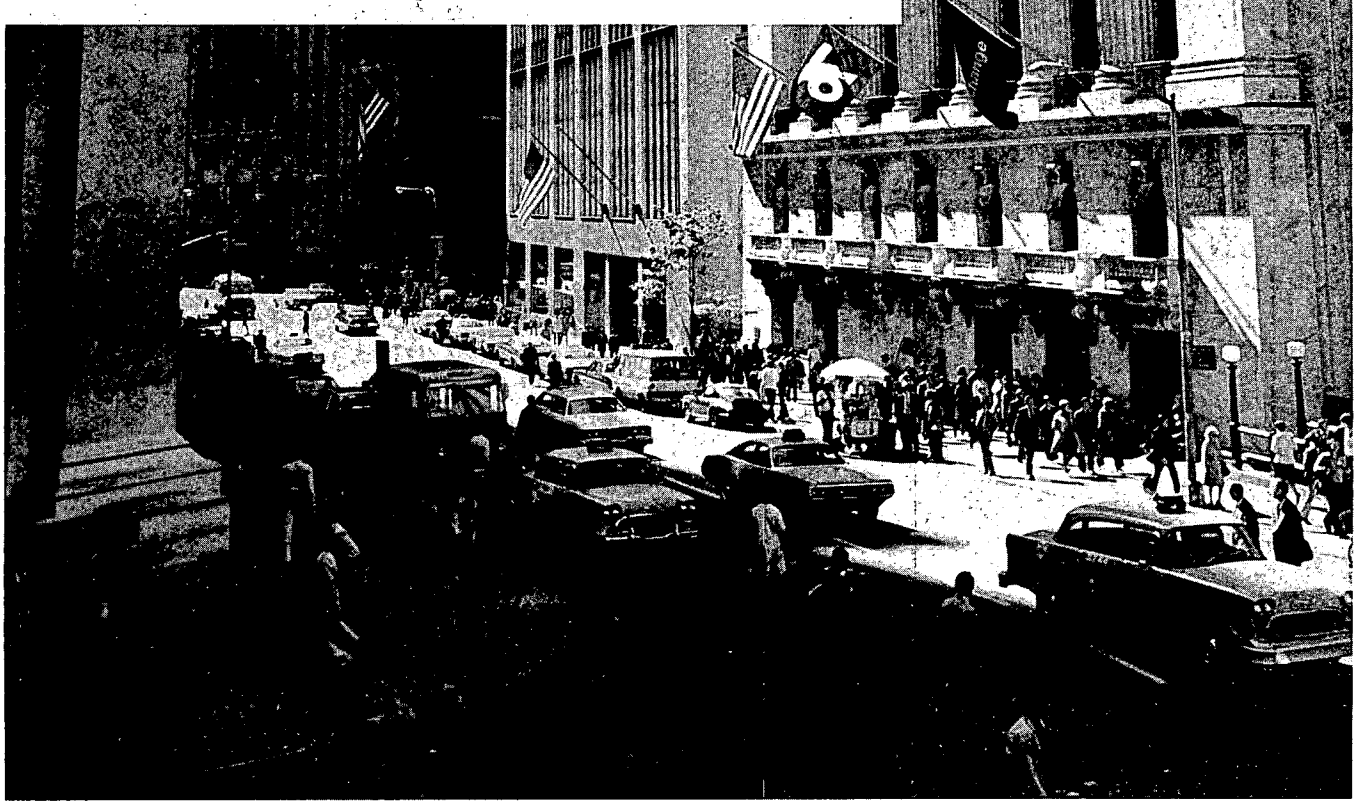
wavelengths of the radiation given off by black bodies of various temperatures. Each curve on the graph represents a black body of a different temperature. As you can see, the sun is also charted, as if it were a black body of 5800°K. This graph shows two things that can be determined from Planck's Law.

First of all you can see that, the higher the temperature of the body, the more radiation it emits. Second, the hotter the body, the more its radiation is concentrated at the shorter wavelengths.

Any black body, whatever its temperature, emits radiation with a broad range of wavelengths. The high point on the curve shows the wavelength for which the intensity is greatest at the particular temperature. This wavelength varies inversely with the temperature of the black body (Wien's Law).

For instance, a light bulb filament ($T \simeq 2900^{\circ}$ K) emits radiation with a peak intensity in the infrared, with wavelengths around 1 micrometer. The sun ($T \simeq 5800^{\circ}$ K) emits radiation most intensely at around 0.5 micrometers. By doubling the temperature we halve the wavelength.

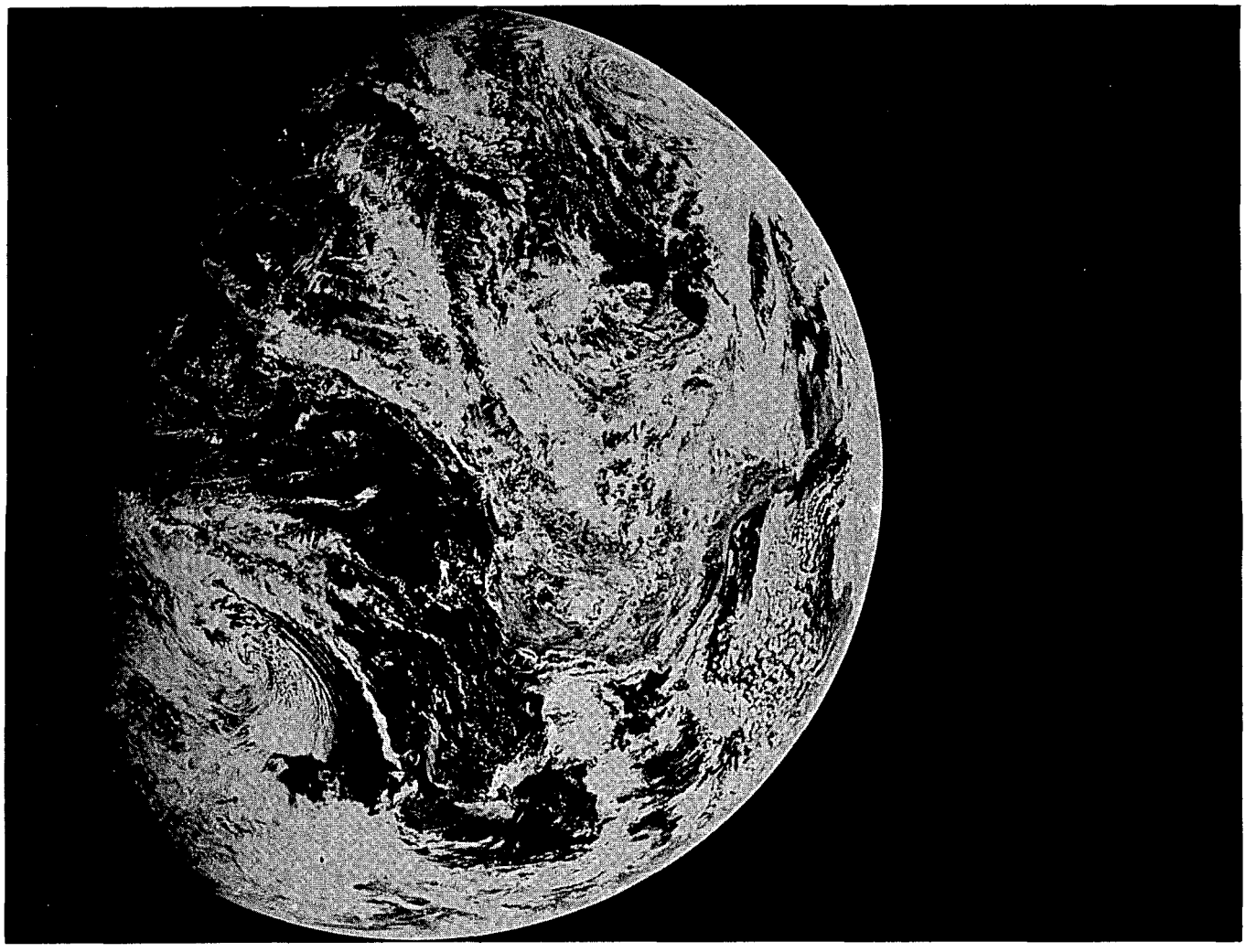
The ideas discussed in the last few pages are the basis for all that follows. The nature of thermal energy and heat flow, and the different means by which thermal energy is transferred (conduction, convection, and radiation) must be clearly understood. These ideas, once in our grasp, provide the basis for any practical use of solar energy.



New York State Department of Commerce

Chapter 4

A Solar Collector in Space



National Aeronautics and Space Administration

The Western Hemisphere, viewed from the Apollo 8 spacecraft.

Most people, seeing earth from outer space for the first time, would be struck by how beautiful it is, how gentle and hospitable its appearance, especially compared to the starkness of the moon. But how many would consider the fact that this planet is a hospitable place primarily because of its ability to collect, transport, and transform the energy from its star, the sun?

When you examine all the factors, earth is revealed as a remarkably good collector of solar energy, and therefore a remarkably hospitable environment for life. In fact, earth has been the model for humans in their attempts to devise successful ways of collecting the sun's energy.

To understand the earth's success as a collector, we must first ask: What are the components of any workable solar collector?

solar collector: a device used to collect the sun's radiation.

The Parts of a Solar Collector

Briefly, a solar collector consists of:

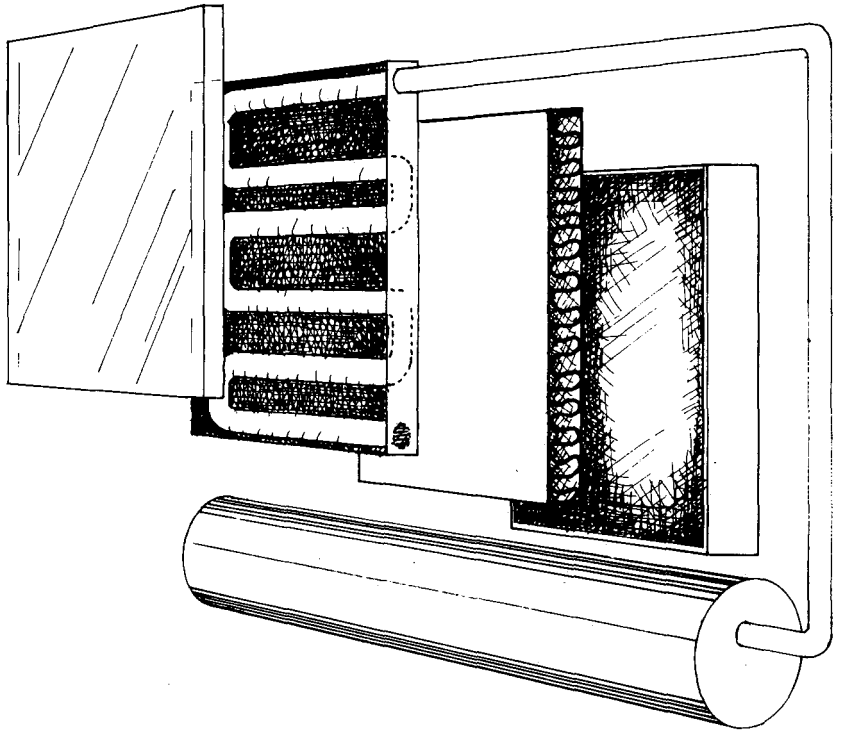
a glazing - a transparent cover, which transmits light but blocks heat

an absorber plate - a dark surface which absorbs light and becomes heated

a transport system - a fluid which passes over the absorber plate through tubes or ducts and carries off the heat

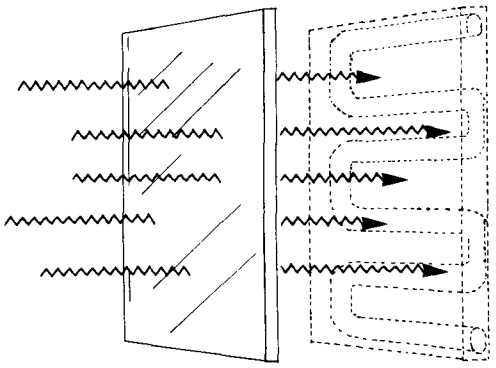
a storage system - a mass in which the heat carried by the transport fluid can be stored for later use

a container - a trap to prevent or minimize loss of collected energy



The collector described here is a simple "flat-plate" type of collector, and of course there are many other ways to collect solar energy. The flat-plate collector will be used in this chapter because it makes a good analogy with the way the earth collects solar energy. As mentioned before, the earth is an excellent collector. Let us see why this is so.

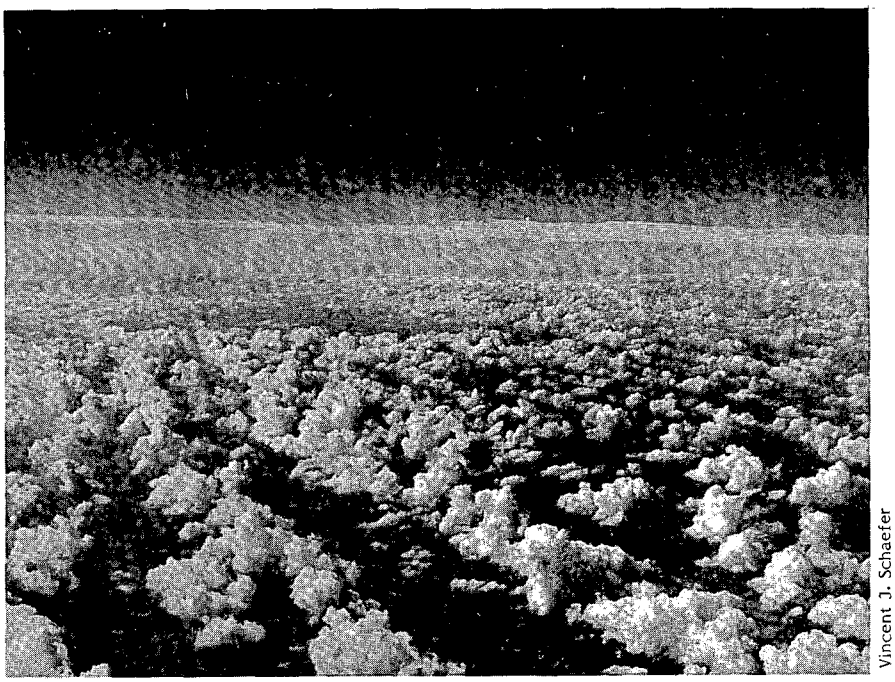
The Glazing



Working from the outside in, a collector starts with a glazing, or transparent cover. Glass, fiberglass, or certain types of plastics are usually used on a manufactured collector; the important thing is that the material admit visible light.

The earth's atmosphere is an excellent glazing. Not only does it admit visible light but, as a bonus, it removes most of the very high-energy radiation which, if not stopped, could destroy all life on earth.

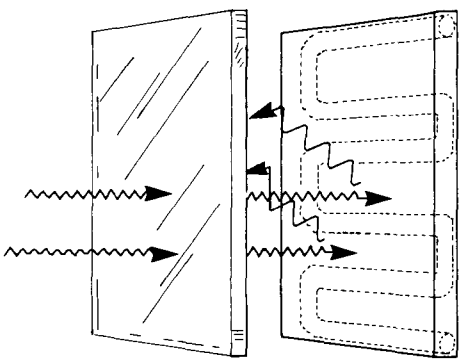
A glazing has another function, however. Not only must it admit incoming radiation; it must also trap outgoing radiation. How is this possible?



Vincent J. Schaefer

To understand the dual function of the glazing, let's see what happens when the incoming energy passes through the glazing and strikes the next component of the collector, the absorber plate.

The Absorber Plate



An absorber plate is usually metal, painted black -- black to absorb the most light, and metal to withstand high temperatures and provide good thermal conduction. (Some plastics can be used also, for lower temperature collectors.)

For the earth's absorber plate, think of the land, the sea, and the lower atmosphere. All three share in the collection of the sun's energy, as well as its transport and storage.

To see how the collector works, remember that visible (medium-wavelength) light is passing through the glazing and striking the plate. When it does so, some is immediately

reflected, but much is absorbed. This energy heats the absorber plate. The absorber plate starts to give off heat but because its temperature is much lower than the sun's, it radiates much longer wavelengths than the visible light wavelengths that it absorbed. These longer, lower-energy wavelengths don't pass through the glazing as readily as the visible light did, so they are trapped inside. This well-known "greenhouse effect" happens to cars left sitting in the sun, and it happens to the earth.

greenhouse effect: the phenomenon whereby the atmosphere admits visible radiation from the sun but blocks infrared radiation emitted by the earth. (See glossary.)

Wavelengths and Wien's Law

You can get a better understanding of the greenhouse effect by going back to Wien's Law, mentioned in Chapter 3:

The wavelength of the radiation emitted most intensely by an object varies inversely with its absolute temperature. (This wavelength will be referred to as λ max).

$$\lambda \max = \frac{\text{a constant } (0.29\text{cm}^{\circ}\text{ K})}{\text{the object's absolute temperature}}$$

The temperature of the sun's surface is about 5800°K so,

$$\lambda \max = \frac{0.29\text{cm}\ ^{\circ}\text{K}}{5800^{\circ}\text{ K}} = 5 \times 10^{-5} \text{ cm or } 0.5\ \mu\text{m}$$

which is the wavelength of visible light.

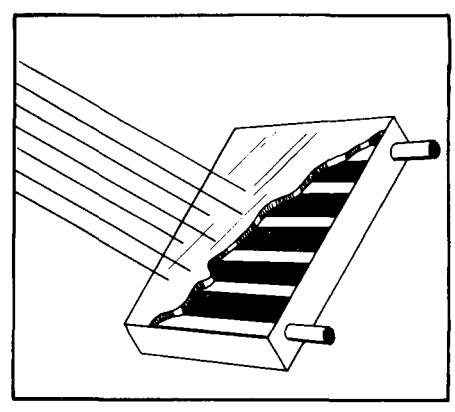
λ represents wavelength; μm means micrometer, a unit often used for electromagnetic wavelengths and equal to 10^{-4} meters. Based on our equation, we can now say that the radiation emitted most intensely by the sun's surface has a wavelength of 0.5 μm, which is in the visible region.

Suppose, though, that the object that absorbs the sun's energy has a much lower temperature, so that even after absorbing the energy it only reaches a temperature of 288°K. That temperature, as a matter of fact, is 15°C (59°F), the approximate mean temperature of earth.

When the earth reradiates energy, then, what wavelength is it giving off most intensely?

$$\lambda \max = \frac{0.29\text{cm}^{\circ}\text{K}}{288^{\circ}\text{K}} = 10^{-3} \text{ cm or } 10\ \mu\text{m}$$

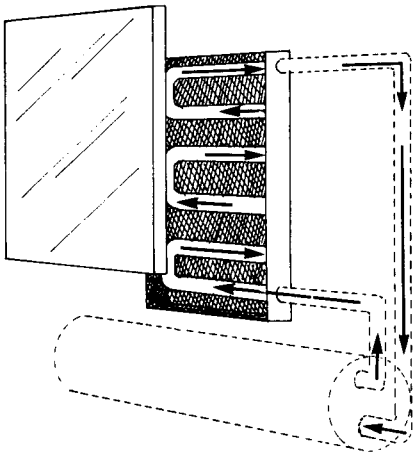
A wave 10 micrometers long is in the middle of the infrared region. The earth's atmosphere, like any good glazing, traps wavelengths in that range quite effectively. The effect is to smooth out the temperature fluctuations, which would otherwise occur between day and night.



A properly oriented collector is tilted so that the sun's rays strike it perpendicularly. In the same way, the regions of the earth that are along the equator are most nearly perpendicular to the sun and therefore are the most effective area for collecting the sun's energy.

The question that comes to mind is: Why doesn't the absorber plate keep getting hotter and hotter until it melts down or achieves such a high temperature that it starts to reradiate as much as it collects? Why doesn't the earth's equatorial region get hotter and hotter as compared with the rest of the earth? The answer lies in the energy transport system.

The Energy Transport System



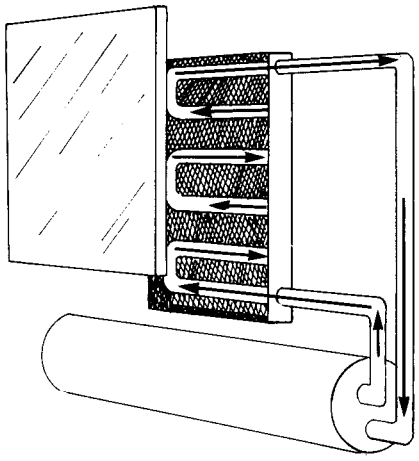
Over, under, in, or attached to the absorber plate are tubes or ducts through which a fluid is circulated. The fluid could be air, water, or another fluid treated to prevent freezing or corrosion. It enters one end of the collector, circulates through the tubes or ducts, and goes out the other end, taking a lot of thermal energy from the absorber plate with it. Thus the absorber plate is continually ready to absorb solar energy.

The earth uses both air and water as fluids in its energy transport system. The convection of heated air which causes our winds and weather fronts, and the convection of heated water which causes our ocean currents, power the earth's natural circulation system.

With a manufactured solar collector, a fan or pump may be necessary to circulate the fluid. The user has to guard against the fluid freezing or corroding the system. When these complexities are considered, we have to admire the reliability of the earth's energy transport system and are less apt to wonder at the occasional tornado, hurricane, or heat wave. They are all part of the big picture of energy transport on earth, moving heat from the equator to the polar regions.

Another factor in this big picture of earth as a solar collector is the earth's rotation. Dealing with the dark hours of every day is one of the major challenges of a solar collector system, and this problem makes the need for energy storage obvious.

The Energy Storage Medium



The heated fluid that leaves the collector has to go someplace -- but where? It can, of course, go directly to where it will be used: the living space, the grain dryer, the domestic hot water tank, or wherever. In the process, the energy may be transferred from one fluid to another through the use of a heat exchanger (which will be described in more detail in later chapters).

A fully effective system will also allow some of the energy to be stored during the sunniest hours and tapped during the coldest hours of night. Heat can be stored in a well-insulated water tank, a bin of rocks, pebbles, or sand, a wall of concrete blocks, or even in "phase change" substances like paraffin, eutectic salts, and salt hydrates which melt or evaporate when heated and then release the heat later when they return to their original state.

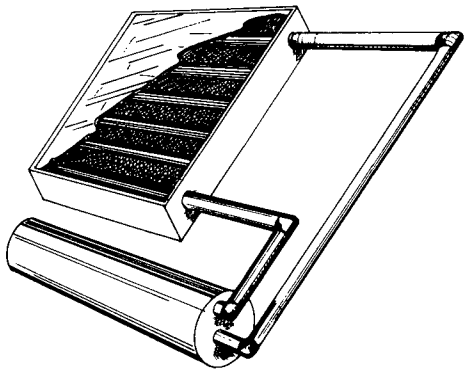
phase change (change of state): the change of a material from one phase to another, i.e., gas to liquid or liquid to solid. (See glossary.)

These methods for storing energy should give us some ideas as to how the earth stores its solar energy. The land, of course -- mountains, deserts, plains -- absorbs much energy during the daytime, but it also tends to lose its heat rather rapidly after dark. If the land were all we had to rely on, the earth at night would become much colder.

Fortunately, we also have energy storage by water, with the lakes, seas, and oceans holding the heat of the day longer than the land and releasing it more slowly. We also have "phase change" storage in the form of evaporation; large amounts of solar energy are stored in the lower atmosphere in the form of water vapor.

The Container

For a manufactured collector to operate efficiently, it must be enclosed (except on the glazed side) in an insulated container to cut energy losses to a minimum. The container, made of metal, fiberglass, or wood, must be resistant to ultraviolet degradation and to temperatures of over 200°C.



This is where the earth as a collector is different from the manufactured solar collector. After all, the manufactured collector is attempting to produce temperatures close to 100°C -- the boiling point of water. If earth became that efficient as a collector, there are few living things that would continue to find it a hospitable dwelling place.

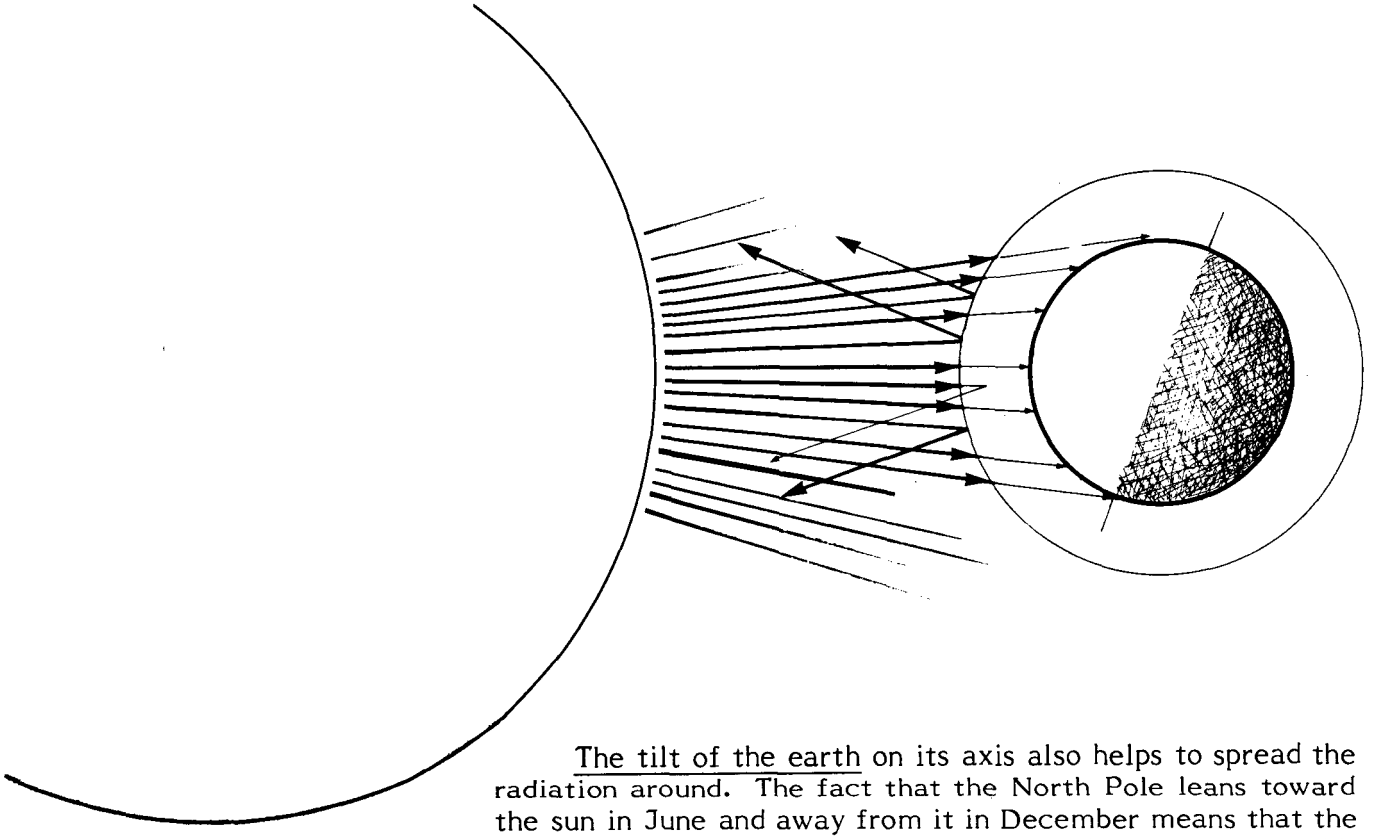
The earth's spherical shape, rotation and tilt, distance from the sun, atmosphere and magnetic field, and circulation patterns of wind and water all prevent it from becoming an unprotected griddle on which life would be fried out of existence in an instant. Unlike a collector which uses a container to achieve high temperatures, the earth system requires much more moderate temperature levels.

Earth: a Controlled Collector

If we take a look at the earth's collector system from the outside, we find that solar energy is arriving at the side of the earth facing the sun at an average rate of 1350 watts/meter^2 , the solar constant. A number of factors impinge on that constant, however, and help to maintain the system's moderate temperatures.

In the first place, 1350 watts/m^2 is the rate at which energy strikes an area perpendicular to the sun. But because of the spherical shape of the earth, little of it is perpendicular to the sun's rays. Most of the radiation strikes at an angle, spreading and reducing the energy received at a given point.

Moreover, the point on the earth that is perpendicular to the sun is constantly changing, due to the earth's rotation. In a sense, the sun is always rising for someone and setting for someone else. No one receives the sun's fullest intensity for more than a short time.



The tilt of the earth on its axis also helps to spread the radiation around. The fact that the North Pole leans toward the sun in June and away from it in December means that the sun is perpendicular to different "bands" of the earth's surface at different times of year.

The distance of the sun from the earth's path around it is important too. Who knows what life on earth would be like if the globe swung much closer to the sun or much farther away in its annual orbit? But that distance varies only 3% throughout the year, not enough to change very significantly the radiation received.

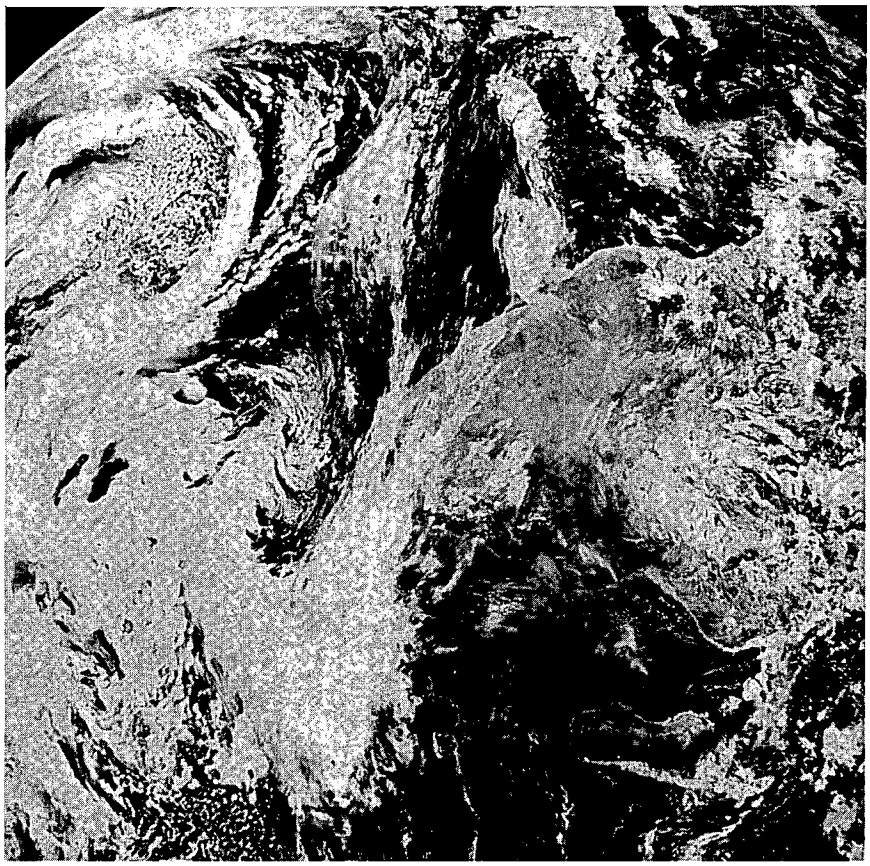
Next, the earth has a kind of double shield to temper radiation and particle bombardment from the sun. The atmosphere's role in reducing the intensity of the solar beam has already been mentioned, and will be discussed in detail in the next chapter. (Practices that threaten to alter the atmosphere may also jeopardize the earth's delicate equilibrium as a collector.) The other layer of the shield is the earth's magnetic field, which actually deflects the high-speed particles of the solar wind, that extension into space of the sun's corona which buffets the upper atmosphere.

Finally, the winds and water currents of the earth help to circulate energy from the earth's efficient equatorial collection zones to the polar zones that collect the least radiation.

Earth: a Solar Laboratory

Over the centuries, humans have learned many practical and ingenious ways of taking advantage of solar energy. Usually, their inspiration has come from observing the world

around them and seeing how the earth itself collects, transports, and stores that essential energy. It makes sense, then, to begin the study of solar energy with an examination of the complex and beautiful steady-state solar collector system that is our planet. The next few chapters will explore that system in greater detail, showing how the earth obtains the energy and maintains the equilibrium that make it such a hospitable environment for life.



National Aeronautics and Space Administration

Southern Africa and Antarctica, photographed by the Apollo 17 crew.

Chapter 5

The Tented Sky

Vincent J. Schaefer

Children sometimes think of the sky as a roof; our early ancestors spoke of it as a dome or tent. Science has taught us that such perceptions are mistaken, that when we look up we are actually looking out into space, through continuous layers of colorless gas. In a sense, though, the childhood metaphor is a correct one. The sky, or more scientifically, the atmosphere, does function protectively, like a roof. Because of its composition it admits what is needed, traps what is beneficial, and excludes what is dangerous. Thus it makes an effective glazing for our solar collector -- earth.

The Structure of the Atmosphere

A brief survey of the structure of the earth's atmosphere is necessary before we can understand just how the glazing works. Let's begin at the edges of the earth's atmosphere where solar radiation strikes, at the full force of the solar constant, on its way toward earth.

The Exosphere, the outermost layer, is composed mostly of the lightest gases, helium and hydrogen. This very low-density layer extends into outer space.

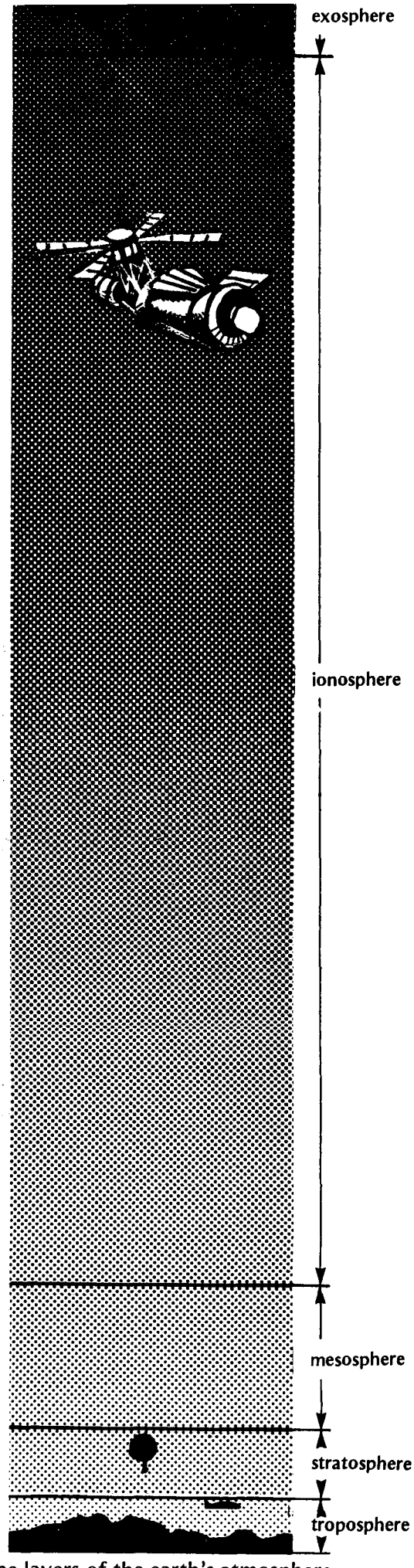
The Thermosphere or Ionosphere starts at about 500 kilometers from earth and descends to within 80 kilometers of earth. Like the sun's corona this area is "hot" because of intense particle activity. Here molecules of gas are being continuously bombarded by high-energy solar radiation, which results in ionized gases. During a solar flare, the temperature may rise to over 1700°C. But as we descend through the ionosphere the temperature drops to near 100°C.

> ionization: process by which a neutral atom gains electrons and acquires a negative charge.

The Mesophere or middle layer, extending from about 80 to about 45 kilometers from earth, has gradually increasing pressure and temperature. Here the two gases associated with life, oxygen and nitrogen, are the most plentiful.

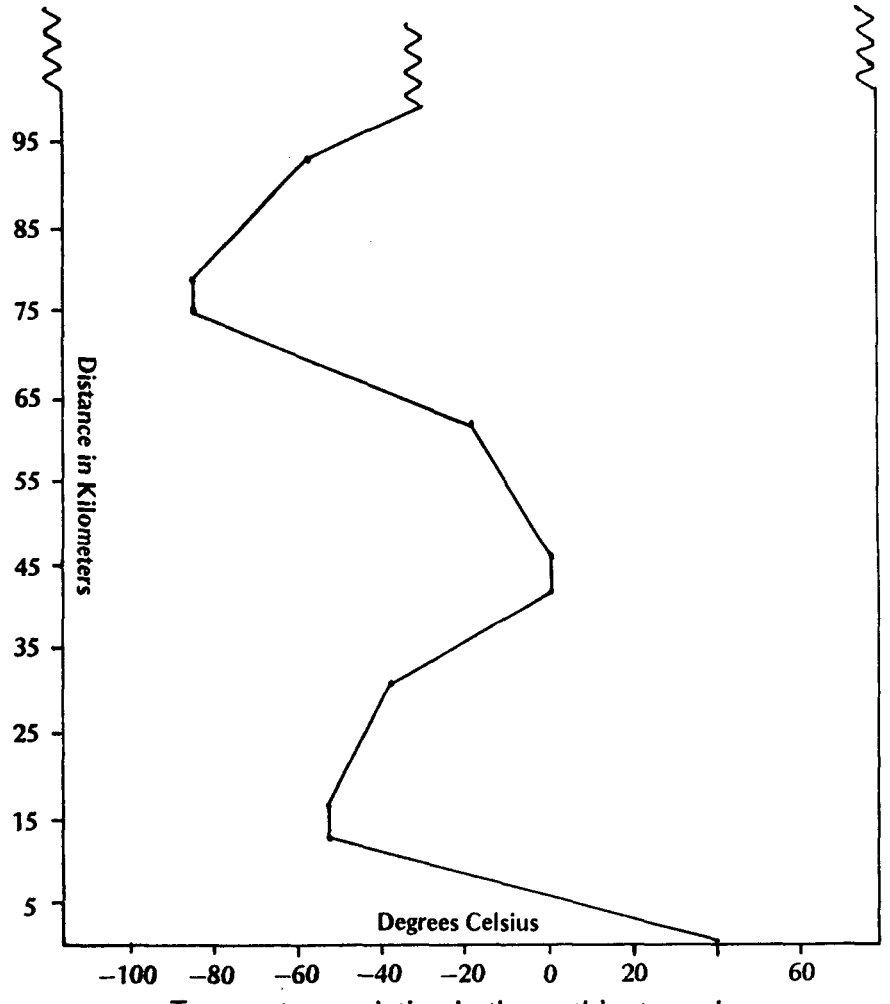
The Stratosphere, at its outer edges 45 kilometers from earth, has a density 1/1000 of that found at sea level. We have descended more than 90% of the distance through our atmosphere toward earth. Yet in terms of density, more than 99% of the mass of the atmosphere remains between us and the ground. We now encounter ozone, carbon dioxide, argon, and other gases (as well as the gases mentioned above), but there is still very little water vapor and no clouds.

The Troposphere, starting 15 kilometers above sea level, is the densest layer of the earth's atmosphere. Seventy-five percent of the atmosphere's mass is here, pulled from below by gravity. This is also the region of the greatest apparent atmospheric activity: convection, evaporation and condensation, clouds, thunder and lightning, and all forms of "weather." In the highest levels of the atmosphere the gases tend to concentrate in layers, depending on their weights. But in the troposphere, because of all the activity there, gases are mixed.



The layers of the earth's atmosphere

Now that we're aware of the basic structure of the atmosphere, let's consider its protective function. You'll notice from the graph below that the temperature of the atmosphere does not change consistently. In fact, the temperature seems to rise and fall rather arbitrarily, defining various regions, as shown on the graph.



Temperature variation in the earth's atmosphere

There is a good reason for these swings in temperature. Wherever they occur they indicate a reaction between solar radiation and the gases which are absorbing it. The heat generated by these reactions is what we see on the graph.

Incoming Radiation

Before it reaches the atmosphere there is very little loss in the amount of radiation emitted by the sun. The full spectrum of electromagnetic radiation strikes the exosphere: radio, infrared, visible, ultraviolet, x-ray, and gamma radiation. Of these varieties of radiation some wavelengths are beneficial and necessary to living organisms, and some are actually harmful. Fortunately, our atmosphere is composed of elements that can selectively absorb most of the dangerous radiation without interfering with the beneficial radiation.

To begin with, as radiation passes through the atmosphere it begins to encounter widely spaced oxygen molecules (O_2). The shortest, highest-energy wavelengths (0.18 micrometers or shorter) collide with the oxygen molecules and are absorbed. This absorption causes the oxygen molecules (O_2) to break up producing atomic oxygen (O). Some of the atomic oxygen combines with O_2 molecules to form ozone (O_3). Ozone has a weak enough bond so that it is then broken into O_2 and atomic oxygen again by wavelengths up to 0.32 micrometers, thereby absorbing those wavelengths in the ultraviolet range that are considered harmful to life.

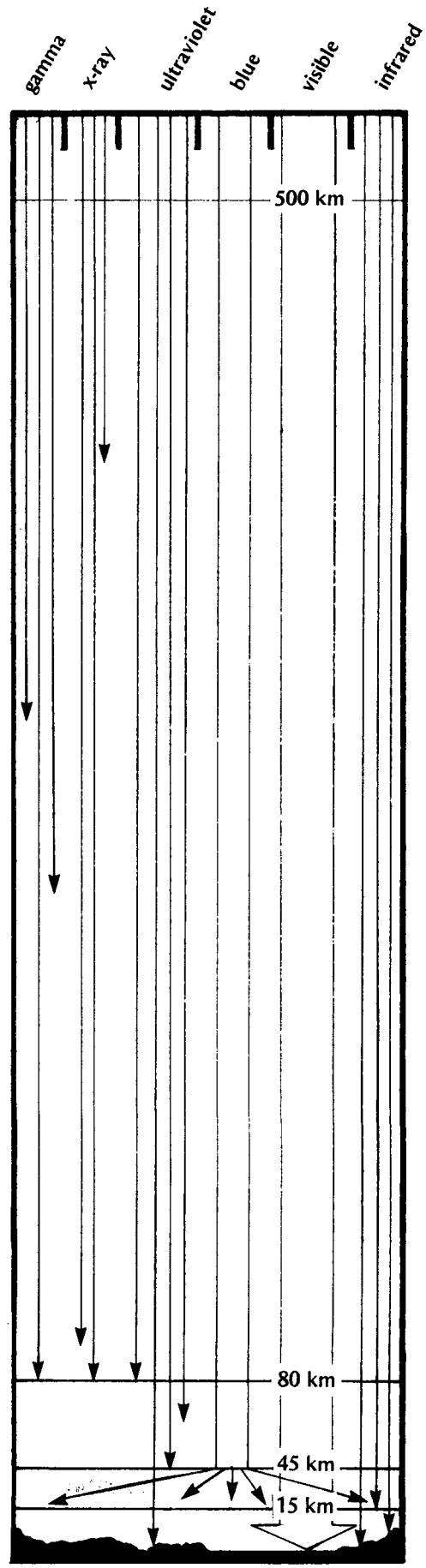
At around 20-50 km above earth, then, there is a layer of O, O_2, and O_3 which continuously dissociates and recombines, absorbing almost all of the very high-energy wavelengths of solar radiation in the process. This absorption transforms high-energy radiation to heat, which causes the rise in temperature noted on the graph. So effective are the reactions just described that very little short wavelength, high-energy radiation reaches the earth's surface.

Remember, though, that the atmosphere's gases react selectively with certain wavelengths of solar radiation. If the atmosphere is like a protective wall, then there is a window in that wall. That "window" allows most of the visible light wavelengths that are essential to life and growth to enter without interference. There is some scattering of the visible wavelengths, especially the shorter wavelengths (blue), creating our familiar blue sky.

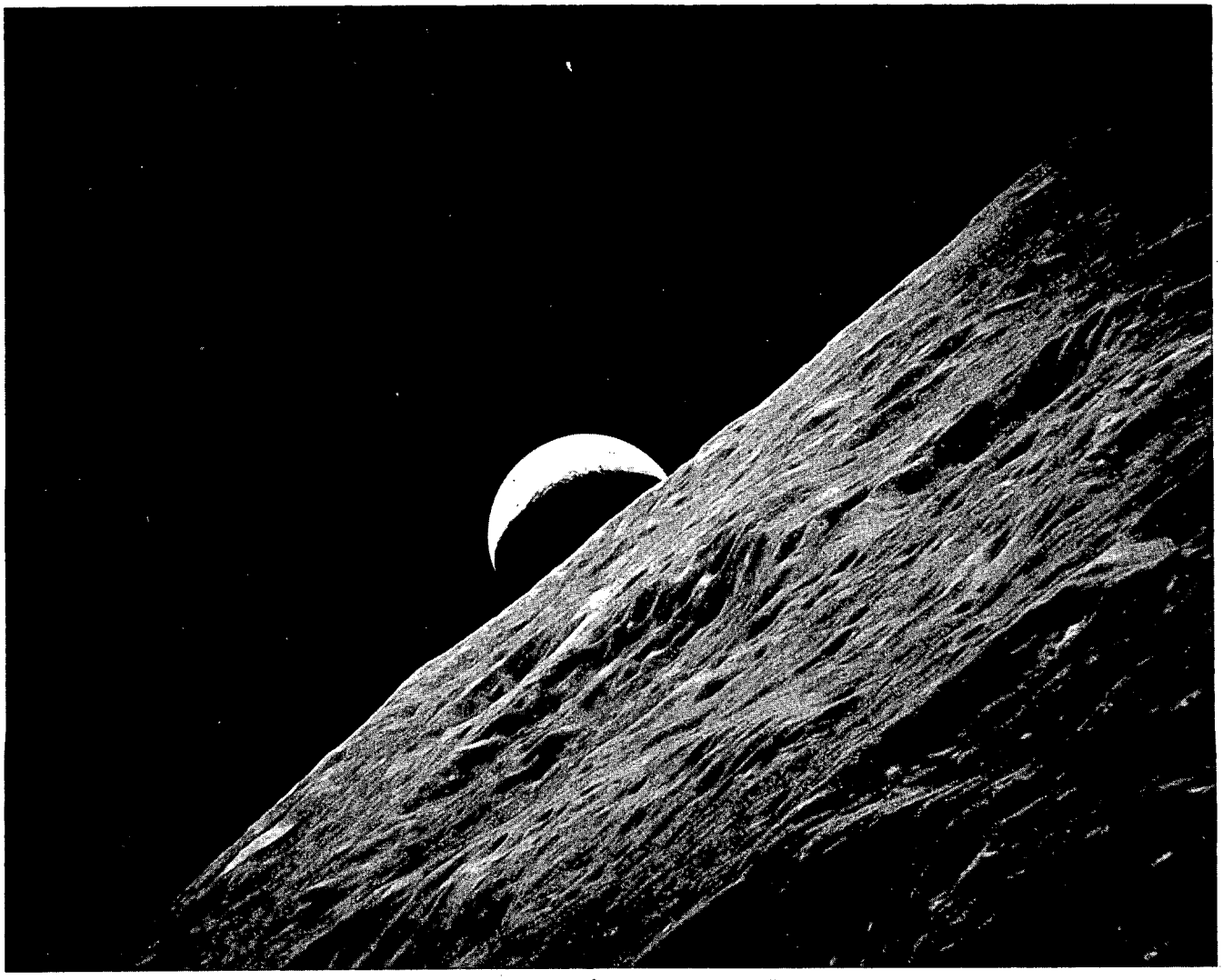
With the longer (infrared) wavelengths, there is again some useful interference. Water vapor and carbon dioxide in the lower atmosphere absorb and store a large amount of incoming infrared.

As solar radiation passes through the troposphere other factors start to impinge: clouds of various kinds, dust particles, smog and pollutants. The "bottom line" is that only about two thirds of the original solar radiation is available for absorption and use at the earth's surface. Recent studies give a figure of 1 kilowatt per square meter at sea level when there is direct sunlight and the sun is directly overhead. (Remember that the solar constant outside the atmosphere is 1.35 kilowatts/m^2.)

Keep in mind that only half of the earth's surface is receiving solar radiation at any given time, however. In fact even less than half is effectively exposed to collectable radiation at one time. This raises the complex question of reflection and radiation of light and heat from the earth, followed by rereflection and reradiation from cloud cover, water vapor, and carbon dioxide. The earth's equilibrium is not a simple matter of in-and-out. If it were, we'd get awfully cold when the sun disappears below the horizon.



Absorption of solar radiation by the atmosphere

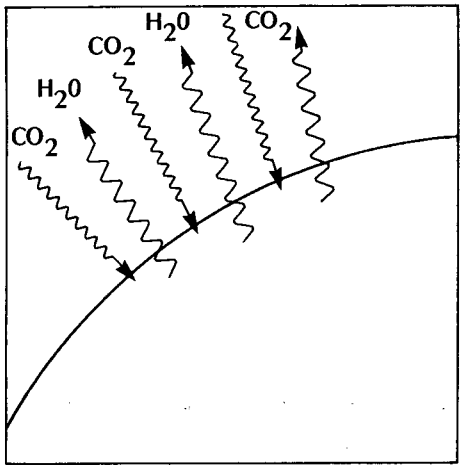


National Aeronautics and Space Administration

The lunar surface, shown in this unusual view of an "earthrise," experiences extremes of heat and cold because of its lack of atmosphere.

Outgoing Radiation

So far we have discussed the atmosphere only in terms of incoming radiation, but this is only half the story. Remember that the earth receives radiation on only part of its surface, but gives up radiation continuously over the whole surface. As a tent to trap outgoing radiation, the atmosphere maintains a life-sustaining temperature on earth, day and night.



Much of the radiation from the sun is at wavelengths of less than 4 micrometers, because of the tremendous heat of its source. After the visible radiation that reaches earth is absorbed by the lower-temperature earth, it is reradiated at longer wavelengths, from 4 to 70 micrometers. Most of these longer wavelengths are easily absorbed by the water vapor and carbon dioxide that are abundant in the troposphere. This keeps the longer wavelength energy close to the earth's surface as heat, which is stored during the day and given off as the temperature drops at night.

Evaporation is also an extremely important factor in maintaining and moderating the earth's temperature, and will be discussed at greater length in Chapter 6.

evaporation: the change of a liquid to a gas with the addition of latent heat. (See glossary.)

The earth does not lie in space naked and unprotected; it is tented and wrapped in the effective layers of its atmosphere. The atmosphere consists of just the right elements in the right locations: oxygen in its various forms to absorb dangerous high-energy radiation far above the earth, and water vapor and carbon dioxide to absorb life-sustaining energy as heat and trap it close to the earth's surface.

This has been a brief and somewhat oversimplified explanation of how the atmosphere works as a glazing. The following chapters will look more closely at what happens to the energy collected by earth, and how equilibrium is maintained and life is sustained under the tented sky.

National Aeronautics and Space Administration

Chapter 6

A Complex Equilibrium

In the simplest situations there may be unseen complexities. You lie on your towel on the beach, waiting for the sun to break through the clouds. Your body maintains its normal temperature, gives off its own normal radiation. In a moment the sun bursts from behind the clouds, warming your back. A breeze cools you briefly, then the heat builds up. The water from your last dip in the lake evaporates quickly, carrying some of the heat of your skin into the air. You roll over, your heated skin now in shadow, warming the towel and sand beneath you.

Who can say, from the simple scene just described, what energy exchanges were taking place? Could you calculate how much of the sun's energy your body absorbed and how much went to the breeze, the evaporating water, and the sand under you? The answers to these questions would be hard to calculate.

Imagine then the complexity of the earth as a collector, with its atmosphere, bodies of water, moving currents of sea and air, daily rotations and yearly revolutions. Still, we have one fact on which to base our calculations. We know that, at least in recent history, the earth has maintained a general temperature equilibrium, neither losing nor gaining much from its average annual temperature of $15^{\circ}C$.

N.Y.S. Department of Commerce

Earth-Atmosphere Heat Balance

Given that the earth maintains a constant average annual temperature, we can assume that on the average, the amount of energy going out is equal to the amount coming in. Of course, that doesn't mean that all incoming solar radiation is immediately reradiated. A given amount of solar energy may feed a leaf which eventually dies, falls to the ground, decays, and thousands of years later becomes coal which is burned, giving off heat which escapes into the atmosphere and then into space. The path may be a long one, but the equilibrium is maintained.

heat balance: the equilibrium between energy from the sun received by the earth-atmosphere system and energy emitted by the earth-atmosphere system.

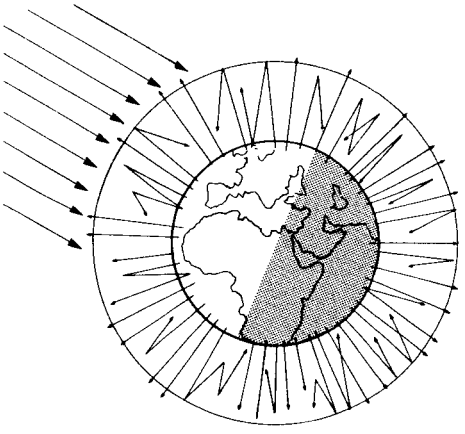
Let's look at this equilibrium in greater detail.

In and Out and 'Round and 'Round

Remember that we said, in Chapter 5, that the story of solar radiation and the earth was not a simple case of in-and-out. Because the atmosphere is an effective glazing, a high percentage of the heat absorbed and reradiated by the earth and atmosphere is trapped in the lower atmosphere and returned to earth, which radiates it to the atmosphere again, and the cycle goes on and on, with small losses to space each time.

At any given time then, the earth itself is giving off more energy into the atmosphere than it is getting from direct sunlight. It does this because so much of the energy it is losing is bounced right back to it from the atmosphere.

But if you look at the earth and the atmosphere as a unified system, you find that the total system is giving off just the same amount of energy as it gets from the sun.

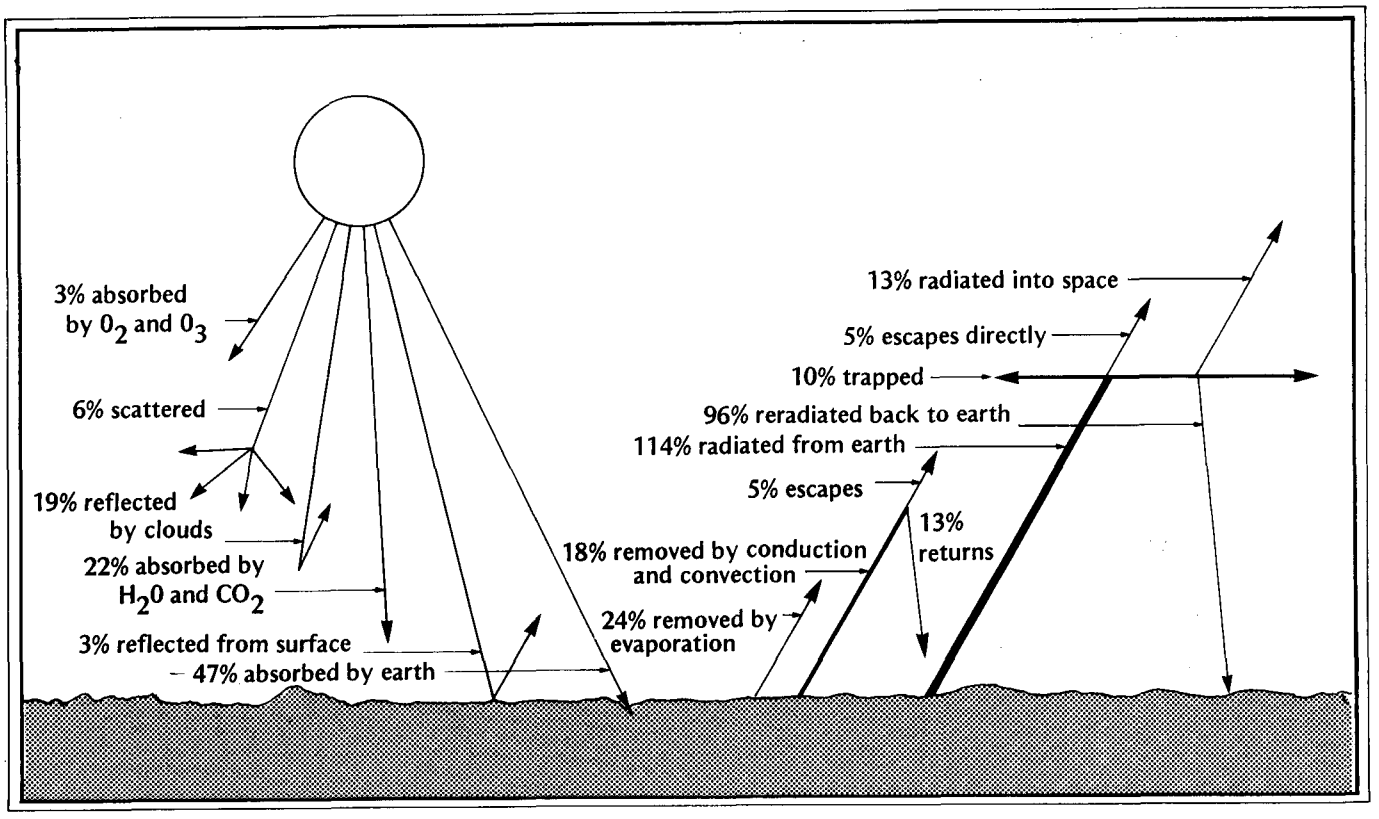


There are two balancing acts going on, then. One is the balance between the earth and its atmosphere, and the other is the balance between the sun and the earth-atmosphere system as a whole. If you see this as two separate equations, you can then understand how the earth-atmosphere system is giving off 100% of the energy it receives from the sun at the same time that the earth is releasing to the atmosphere 156% of the radiation the sun is giving to the earth-atmosphere system at any given moment.

The Big Picture

The diagram on the next page shows the two complex and interlocking heat balances that we have been describing: the one between the earth and its atmosphere, and the other between the sun and the total earth-atmosphere system.

The numbers given are approximations, and may not agree precisely with those given in other sources. They are provided to help you see the proportions that are involved.



Atmospheric Depletion of the Solar Beam

Start by examining the solar beam as it approaches earth. Until it reaches our atmosphere, 100% of it is transmitted through space. When it reaches our atmosphere, as we know, depletion of the beam begins. Some is absorbed by oxygen and ozone reactions. Some wavelengths are scattered. Some radiation is reflected directly back into space by clouds or by the surface of the earth itself. Evaporation of water from clouds, from lakes and oceans, and from plants absorbs a large amount of radiation.

Specifically, as we see in the diagram, about 3% of the solar beam is absorbed by oxygen and ozone reactions, about 22% by water vapor and carbon dioxide. Six percent, mostly blue wavelengths, is scattered by the atmosphere; 19% is reflected by clouds; 3% is reflected by the earth's surface. This leaves about 47% of the original beam that actually reaches and is absorbed by the earth.

But, as mentioned before, direct radiation is not the only source of heat for the earth. Large amounts of heat from absorbed radiation and latent heat released when water vapor condenses are radiated back toward earth. So at any given time, the earth is actually getting more radiation from the atmosphere than it is getting from direct solar radiation.

latent heat: the result of an increase in the heat content of a substance without an associated temperature change; occurs during phase change. (See glossary.)

Thus the earth's surface has to constantly rid itself of heat to maintain equilibrium. Evaporation, as we can see from the diagram, removes 24%.

evaporation: the change of a liquid to a gas with the addition of latent heat. (See glossary.)

Evaporation's Role in Heat Balance

Water and water vapor are such an important part of our earth's equilibrium that they deserve additional comment. As was already mentioned, water vapor absorbs incoming radiation before it reaches earth. Now we find that water removes an even larger amount of radiation from the surface of the earth itself. How does it do all this?

From your study of heat flow you may remember that it takes 1 calorie to raise 1 gram of water 1°C. But to evaporate that gram of water once it reaches the boiling point, much more energy is required, about 540 calories per gram just to overcome the bonding of liquid water and turn it to water vapor. Water thereby "uses up" large amounts of radiation by evaporating. Of course it doesn't really use it up, but rather stores it in the atmosphere as "latent heat". This heat will be released when the water vapor's surroundings fall below the temperature or pressure at which it can stay vaporized. When the vapor becomes liquid again as clouds or dew, the heat released will be radiated in all directions, some into space and some back to the ground.

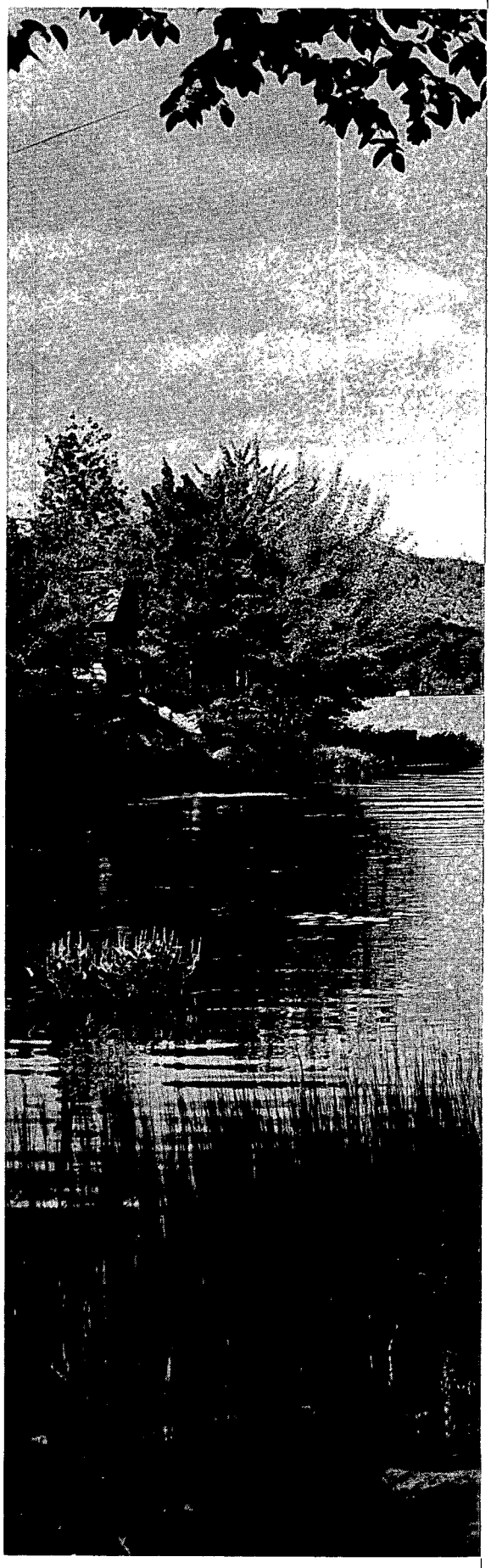
In a later chapter you will read about heat pumps, devices which move heat from one place to another by evaporation and condensation. Heat pumps are modelled after nature's water cycle, which collects heat from the earth's surface through evaporation, moves it (as latent heat in water vapor) by convection, and then releases it at another location by condensation.

> condensation: the change of a gas to a liquid.

The Earth: Absorber, Conductor, and Radiator

The radiation that reaches earth and is not reflected or stored by water evaporation is absorbed by the earth's varied surface.

Some will be absorbed by land masses which will then reradiate that energy. Much of the radiation will fall on bodies of water which, having a higher heat capacity than land, warm up more slowly but also release their heat more slowly. (This is why water temperatures lag behind the seasons; the sea is still cold in late spring, but remains warm into the autumn.) Both land and water will continue to reradiate at night and on cloudy days, moderating the temperature of the atmosphere above them.



New York State Department of Commerce

The air over land and water collects energy from the earth by conduction, and moves it by convection into the upper troposphere, where some is lost but some is radiated back to earth yet again.

Conduction and convection of air heated by the earth's surface remove 18%, but the cycle of conduction-convection will eventually bring 13% back to earth, so only 5% actually escapes.

photosynthesis: synthesis by plants of organic compounds from carbon dioxide and hydrogen in the presence of light. (See glossary.)

Meanwhile, the earth itself is radiating a massive amount of heat directly, an amount equal to 114% of the direct solar radiation aimed toward earth. But only 5% escapes directly; 109% is trapped by water vapor and carbon dioxide. Thirteen percent then gradually escapes into space, but 96% is radiated right back to earth. So the cycle goes on.

Photosynthesis and Heat Balance

Plants play a small but very important role in the heat balance of the earth. Some of the radiation that reaches earth falls on plant life: forests and jungles, plains and farmland, and millions of acres of floating seaweed and algae. Here another kind of storage takes place, through the chemistry of photosynthesis, the process by which plants use the energy of sunlight to manufacture carbohydrates. How long the energy will be stored depends on what happens to the plant. If it is burned or eaten immediately, the energy is released fairly soon. If it dies and decays, it will give off heat slowly. If it is buried for millions of years, it will slowly become coal. The animal life nourished by plants reradiates some of the energy while living and produces natural gas when dead. Plant and animal remains, stored under heat and pressure for 10 million years or more, yield oil. When these slowly produced fuels, coal, gas, and oil, are burned, the last of the energy stored by photosynthesis is given up.

R.A. Fogarty

Threats to Earth-Atmosphere Heat Balance

Air pollution is the presence in the atmosphere of substances which are harmful to living things. Nature itself produces some air pollution, such as plant pollen, volcanic ash, and dust from natural erosion. Generally, however, this natural pollution recycles itself and does not overload the atmosphere.

Not so with man-made pollution. The 19th and 20th centuries have been periods of intense energy consumption and industrialization. Much of today's atmospheric pollution is simply the result of burning fuels:

hydrocarbons from burning petroleum, gasoline, etc.;
sulfur oxides from burning coal;
nitrogen oxides from high-temperature burning in engines;
carbon monoxide from inefficient burning;
carbon dioxide from <u>any</u> burning.

Lead, fluorides, asbestos, and a variety of airborne particles, aerosol droplets, and vapors can be traced to our industrial and energy-intensive way of life. Some of these substances are toxic in the short or long run. But more than that, their sheer quantity affects the way the atmosphere absorbs or transmits the sun's radiation. No one can predict how this may affect the earth's climate, water supply, or vegetation.

The problem is not with pollution itself. The problem is with the <u>rate</u> at which humans are producing pollution: a rate so high that it degrades the air quality around human habitations and threatens the balance of the atmosphere itself.

Vincent J. Schaefer

Keeping Our Balance

Every factor, small or large, plays its part in the heat balance we have been discussing. A hurricane plays a part, and so does a tree. The composition of the atmosphere, the global patterns of air and water movement, and the size and location of land and water masses are all critical factors.

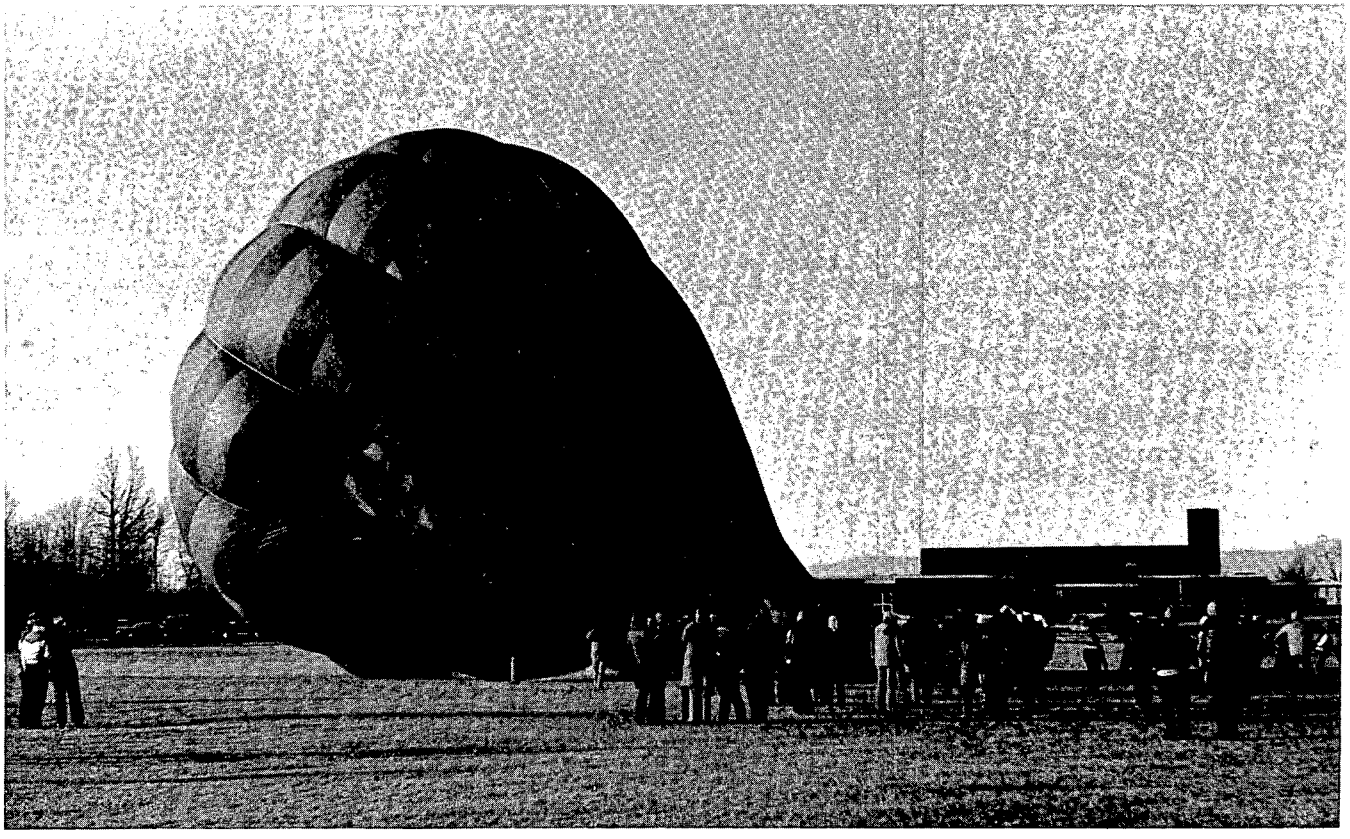
As a sunbather on the beach, maintaining a heat balance should be a matter of concern to you. The consequences of imbalance can be serious: sunburn or sunstroke. Similarly, heat balance between the earth, the atmosphere, and the sun should be of concern to all of us, because if we lose that complex and critical equilibrium it will be more than serious; it will be catastrophic.

Chapter 7

Making It Move

To say that a system is in equilibrium is not to say that the system is static. A thousand parts may be moving; a thousand changes may be occurring. But if all the movements and changes are complementary, balance is maintained. So it is with the earth, a mighty and complex machine. The sun radiates energy and the turning earth receives, spreads, and eventually returns that energy to space.

This chapter will deal with a very important phenomenon: the way the sun's energy gets spread over the earth before it is returned to space. Without this spreading of heat from high solar impact areas (the equator) to low solar impact areas (the poles), the earth could never support life the way it does.



R.A. Fogarty

Hot air balloons show Archimedes' principle at work--except when the wind blows them over!

The key to the whole matter was discovered by Archimedes over 2000 years ago. He found that a body immersed in a fluid is buoyed up by a force equal to the weight of the fluid displaced. Since much of the earth's collecting surface is fluid (air and water), Archimedes' principle proves to be very significant in the operation of the earth as a solar collector.

The Atmosphere:

Vertical Circulation

Although air transmits light comparatively well, it is a relatively poor conductor of heat. As the surface of the earth is heated by the sun, it conducts heat to the air for a few feet directly above it. This air expands because of the more rapid motion of its particles, becomes less dense than the surrounding air, and is buoyed upward by cooler, denser air sliding down and under the warm air.

The parcel of warmed air continues to be buoyed upward and is "unstable" until due to expansion and reradiation it reaches temperature equilibrium with the surrounding air. Then there is no unbalanced buoyant force, and the parcel stops rising.

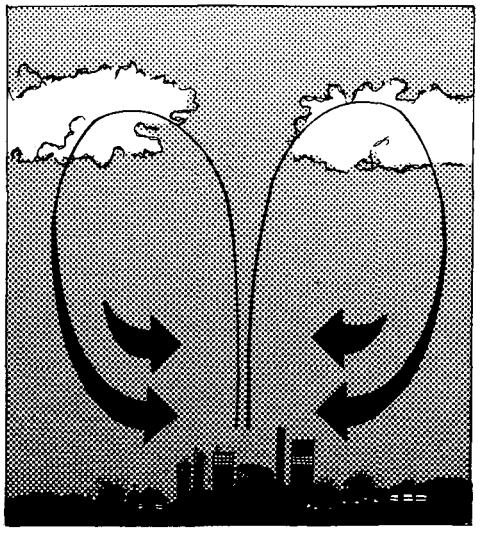
A number of things affect the temperature of the parcel of air as it rises. First, as it leaves the earth's surface, it loses contact with its source of heat. Then, as it gains altitude, the atmospheric pressure drops. This allows the parcel to expand still more by pressing against and working on the surrounding less dense atmosphere. This work that the parcel does on its surroundings causes it to lose energy and therefore its temperature drops. (When a temperature change is brought about by a pressure change without addition or removal of heat, we call the change "adiabatic.")

adiabatic: related to a decrease in temperature due to an increase in volume rather than to any heat flow.

So the heated air loses contact with its heat source, the earth, and also loses energy adiabatically. Besides these two factors, there is also usually some minor mixing with the sinking cooler air around it. So in general, there is a tendency for rising air to cool.

One factor may add heat to this rising parcel of air. If you remember what you've read about evaporation and condensation, you'll realize that the heated air may carry water vapor with it as it rises. When the air parcel cools enough, the vapor in the air will condense, releasing the latent heat that was stored during the evaporation process.

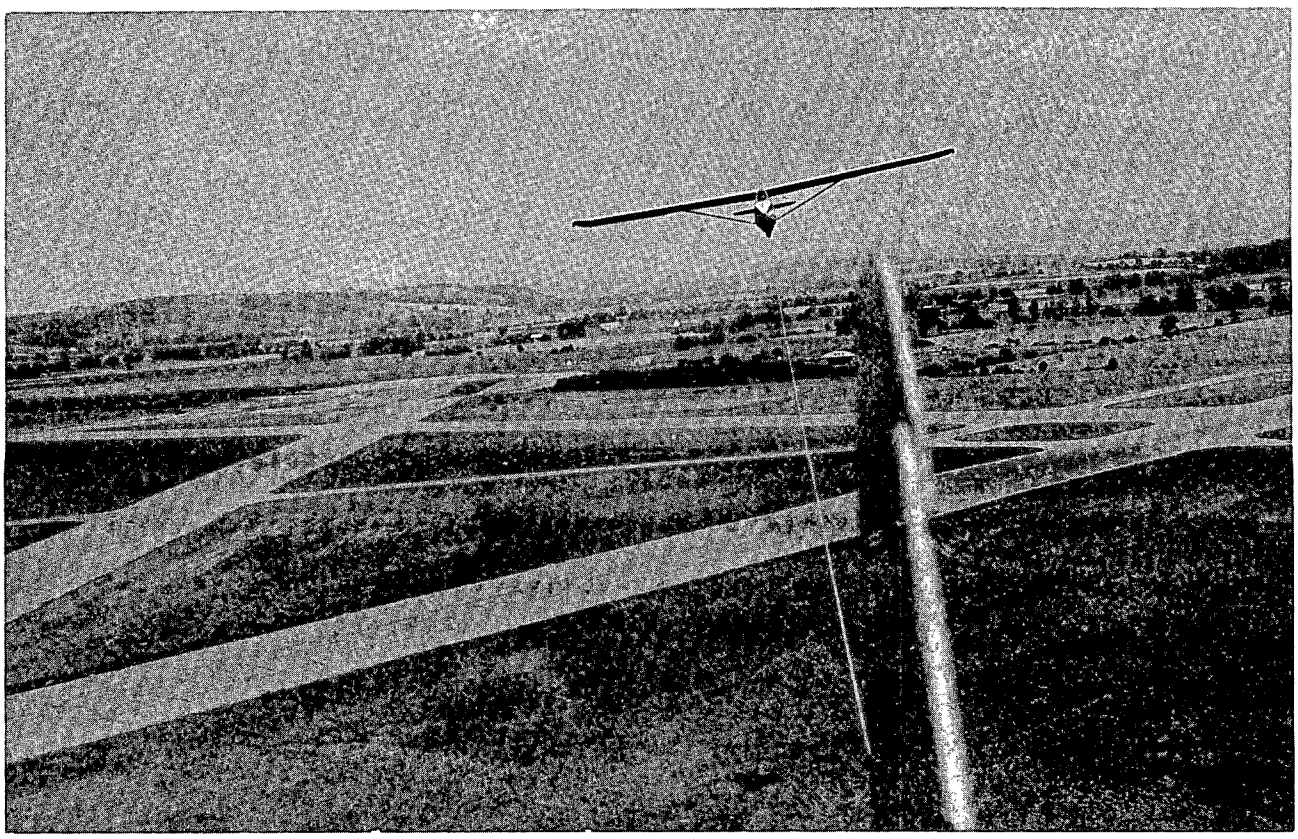
Eventually, however, the heated air will cool enough so that it becomes denser. Meanwhile, the ground-level air is now, in its turn, being heated. The parcel of now cooler, denser air will sink to the ground, buoying up the less dense, heated air. Heating and rising, cooling and sinking, this reciprocal process in the atmosphere creates vertical circulation.



Vertical circulation of heated air

Thermals

Some areas of the earth's surface, because of their color or texture, heat more rapidly than surrounding areas. In turn, they heat the air above them and that air is buoyed up by the surrounding cooler, denser air which moves in to displace it. The resulting localized mass of heated, rising air is called a thermal. When you see a hawk with spread wings circling upward, apparently without effort, he is riding one of these columns of heated, rising air. Gliders also take advantage of thermals to gain altitude and stay aloft.

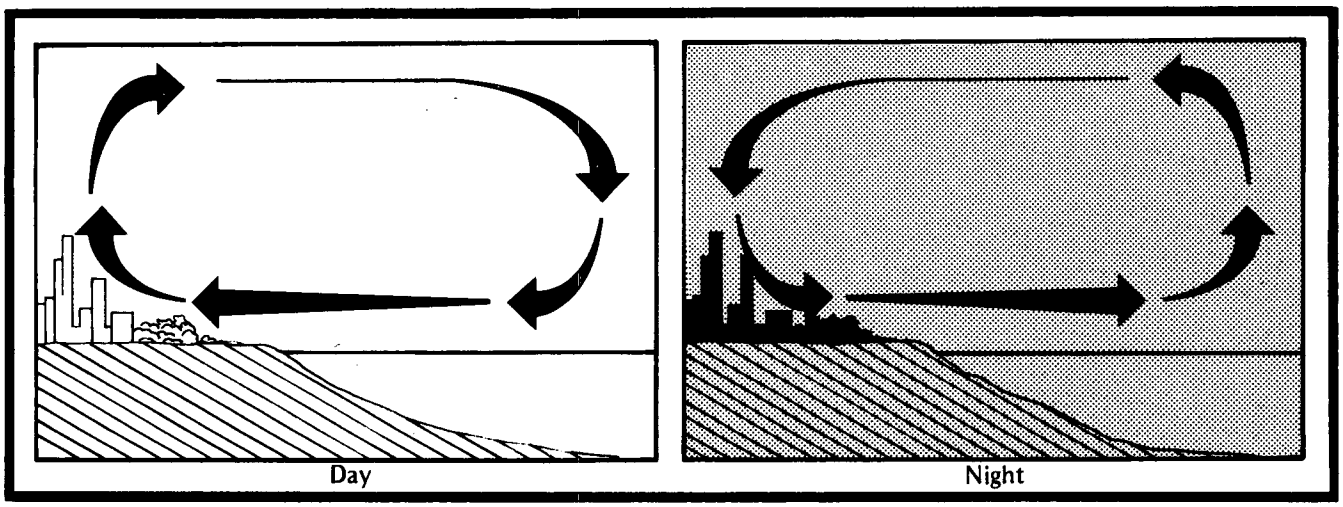


New York State Department of Commerce

Horizontal Circulation

Air moves horizontally for the same basic reason that it moves vertically; sinking air that is cooler, more dense, and therefore has higher pressure, flows in and fills areas where there is less pressure because of heated rising air. These pressure differences occur because of the variations in the surface of the earth.

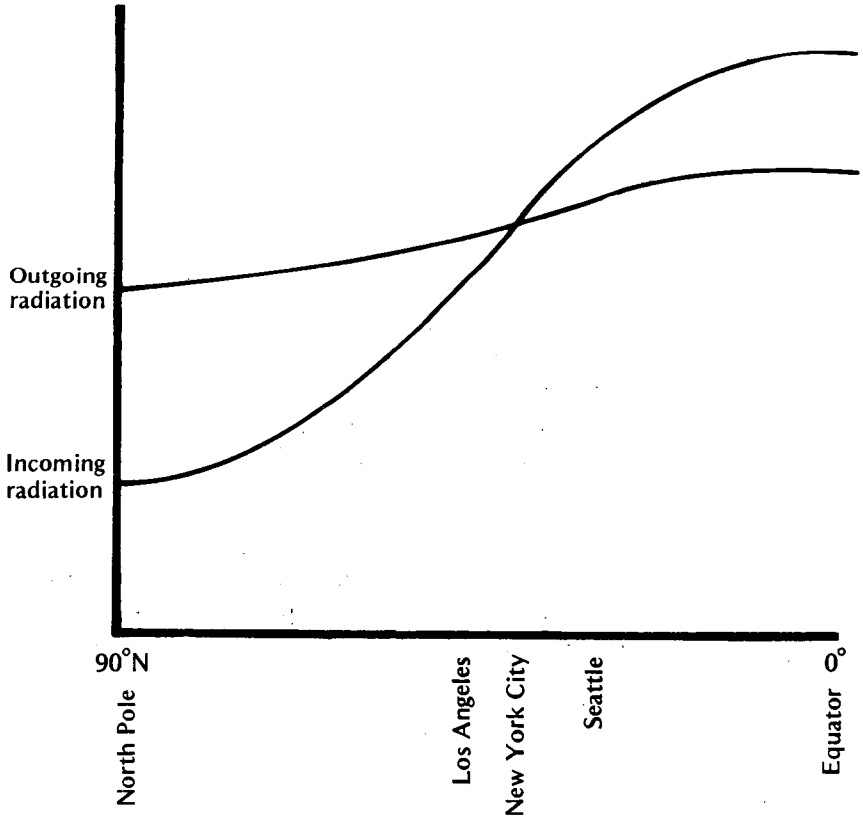
For example, the heat capacity of water is greater than that of land, so it takes much more radiation to raise the temperature of the oceans. Besides, since water is transparent, solar radiation penetrates the oceans more deeply than it does the land and the energy is distributed over a larger mass. The result is that the land heats up more rapidly than the oceans, and heats the air above it more rapidly. As that air expands, cooler air from over the oceans rushes in and equalizes the pressure. (At night just the opposite is true.)

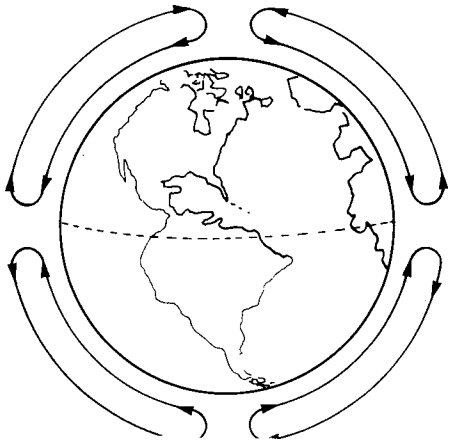


Patterns of air circulation

The Atmosphere's Interlocking Patterns

The vertical and horizontal movements of air help to solve the problem posed by the graph below. Looking at the graph we can see that, for the world as a whole, radiation isn't equally distributed. The north pole doesn't receive enough radiation to keep pace with what it loses. The equator gets more than it can dispose of. Fortunately, the atmosphere provides the solution by acting as a transport medium for heat energy.

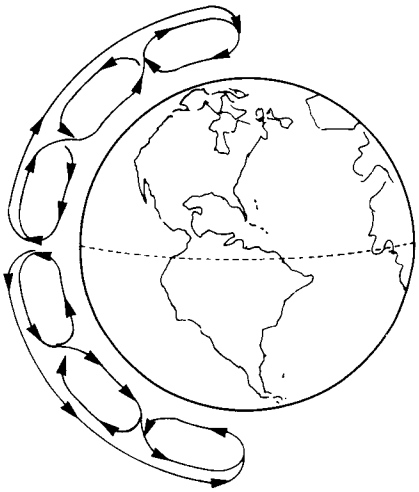




The Hadley cell model of atmospheric circulation

The diagram to the left gives a simplified model for the basic circulation pattern. Heated air at the equator rises, expands, and flows toward the poles where, cooled, it sinks groundward and flows back toward the equator.

Actually, a somewhat better model is the one below. This model shows that while some of the heated air continues toward the poles, some cools and sinks to ground level where it divides. Some of the cooled air flows back toward the equator and some flows onward toward the poles until it encounters yet colder air which buoys it up. This diagram illustrates the "Three-Cell Theory", which assumes that there are three great circulatory loops between the equator and each pole.

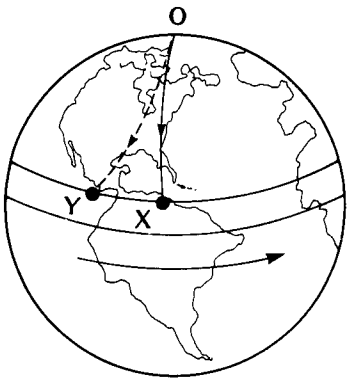


The three-cell model of atmospheric circulation

This theoretical model is modified by several factors. The pressure differences between land and sea that were discussed earlier complicate this simple pattern. The tilt of the earth changes the area receiving maximum radiation in the course of the earth's annual revolution around the sun.

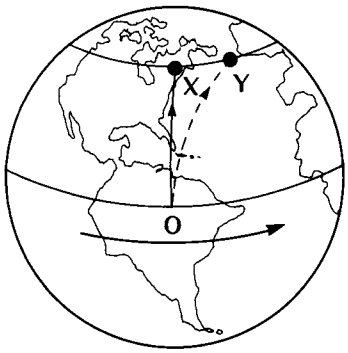
But the major factor affecting the model is the rotation of the earth itself.

The Coriolis Effect



The Coriolis Effect

Because the atmosphere is rather loosely attached to the earth, it "lags behind" the earth's spin. A horizontally moving mass of air may be directed toward a given point, but ends up passing some distance from the point because the point has moved. As you can see from the diagram, an object "O" that starts moving from the north pole toward "X" will end up at "Y". For this reason, winds in the northern hemisphere all appear to curve to the right, while those in the southern hemisphere appear to curve to the left, even though they are actually moving in a straight line.



It makes no difference which way the object initially travels. Even if object "O" is moving north from the equator toward the north pole, it will still appear to curve to the right because of the higher velocity of its starting point. Object "O" starts at a point near the equator where the earth's surface is moving at about 1600 kilometers an hour. It is directed toward point "X", which is closer to the pole and therefore is traveling more slowly, let's say at 800 kilometers an hour. So object "O", because of the more forceful eastward "push" that it starts with will, traveling in a straight line, arrive at "Y". Again, it appears to curve to the right.

The Jet Stream

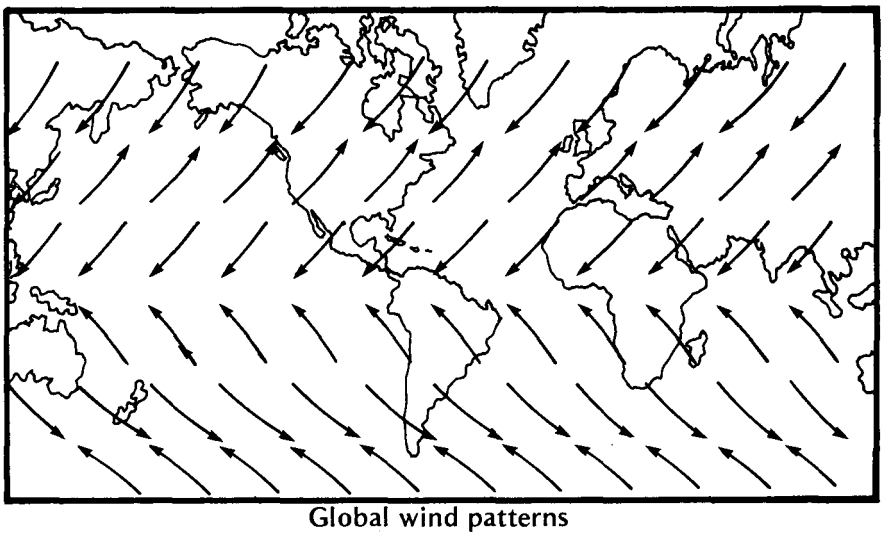
The jet stream is a wide band of high-speed air moving generally from west to east. Located in the upper troposphere, its horizontal movement is created by the meeting of rising warm air with falling cold air. The resulting stream can reach speeds as high as 300 kilometers per hour. The jet stream's winding path shifts somewhat with the seasons. Meteorologists study the jet stream to try to determine seasonal weather patterns.

Vincent J. Schaefer

The Winds of the World

What all this means is that the circulation patterns of the atmosphere are not nearly as simple as in our theoretical model. Instead, here is what happens:

- air over warmer surfaces expands creating areas of low pressure;
- air from areas of high pressure flows in and equalizes the pressure, buoying up the warmer air;
- all the winds created by these pressure differentials are deflected on a curving path, to the right in the northern hemisphere and to the left in the southern hemisphere; and
- the areas of high and low pressure shift somewhat depending on the time of day and the time of year.



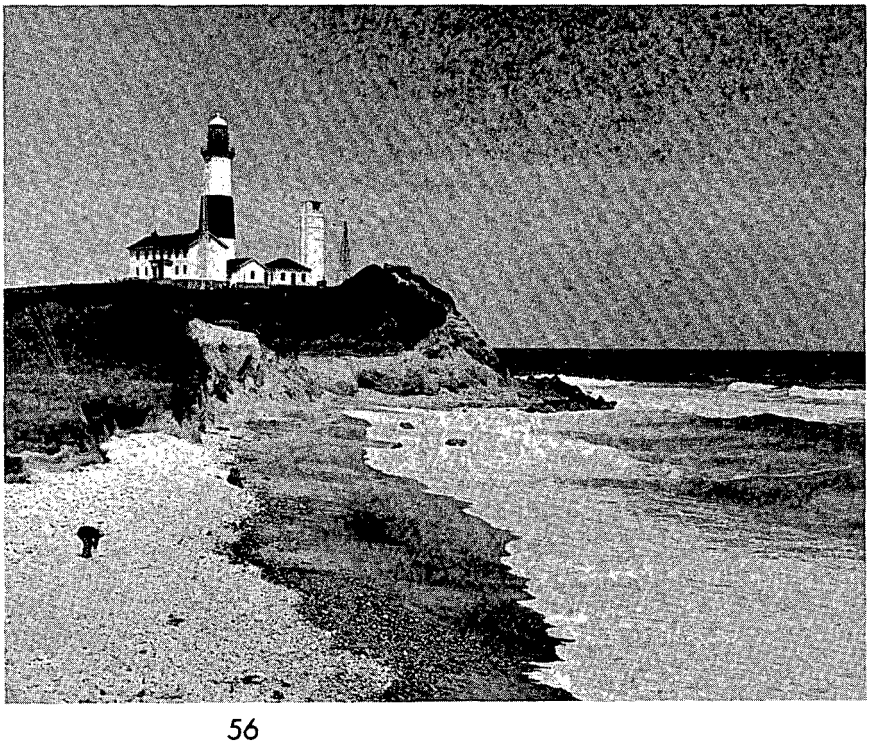
Global wind patterns

All these phenomena contribute to one general effect: heated fluid is moved to areas where it can give up its heat, and cold fluid moves in to replace it.

Water, Ally of the Winds

At the beginning of the chapter, we said that there are two fluids that help to circulate the solar energy collected by the earth. The first is air and the second, of course, is water, primarily the water of the oceans.

The oceans may seem to play a less dramatic role in energy circulation than the atmosphere with its hurricanes, tornadoes, and monsoons. But the oceans are equally important and, indeed, closely allied to the atmosphere in carrying out this task of energy dissipation.



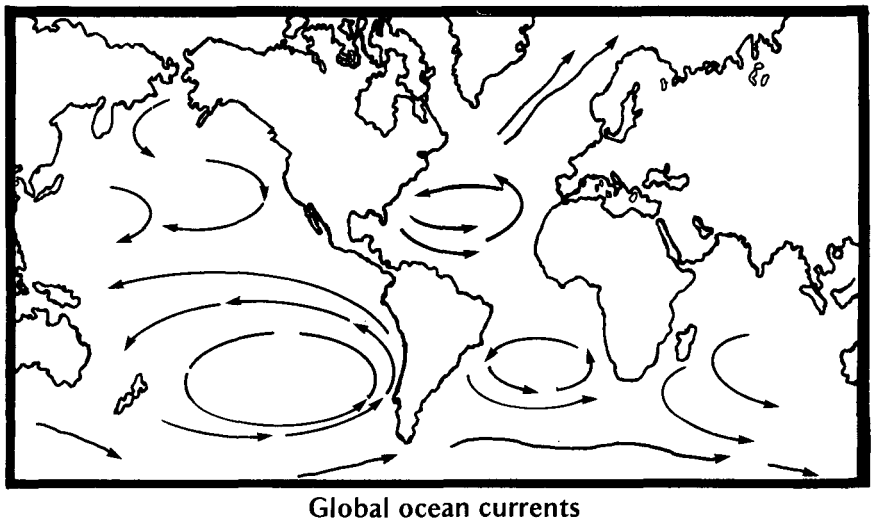
New York State Department of Commerce

In other chapters you've seen how evaporation of water stores a significant amount of solar energy. You've also seen how the high heat capacity of water allows the seas to heat up very slowly and then release that heat slowly, helping to equalize the temperature extremes of day and night and of summer and winter. In this chapter, however, we'll look at how water moves heat mechanically, by the flow of ocean currents.

The Circulation of the Oceans:

Surface Currents

If you look at the map of the oceans' surface currents, and then look back at the map of surface winds, it is clear that there is a mechanical connection between the two. In fact, solar energy drives the winds, and apparently the winds drive the surface currents. The Coriolis effect discussed earlier, whereby the earth's rotation produces a curving wind pattern, also affects the seas, reinforcing the same curving patterns. When the wind drives the water at an angle against the barrier of a continent, the c cular pattern that you see on the map results.

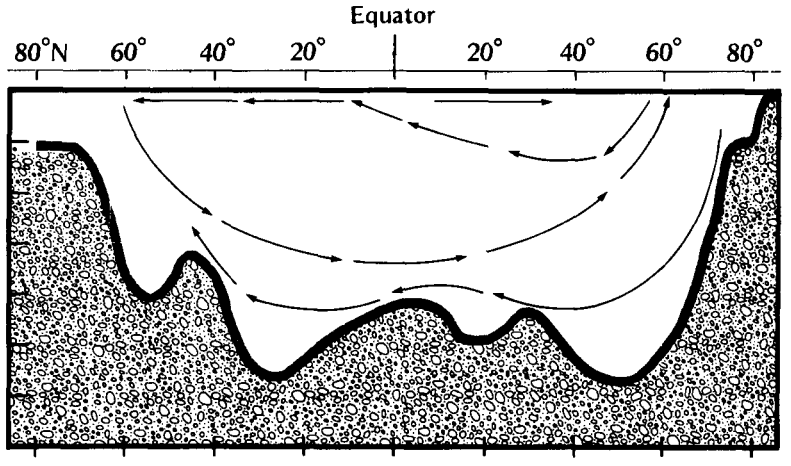


Global ocean currents

This pattern of currents moves heated water from the equatorial area for great distances, and brings cooler water to take its place. (Do you see why the water on the western coast of the North American continent would be rather cold for swimming, while that on the eastern coast would often be warmer?)

Density Currents

The mechanical movement of the oceans' surface is not the only way that water helps to distribute solar energy on the earth. Archimedes' principle works on all fluids, water as well as air. This means that colder, denser water will tend to slide under and buoy up less dense water, which is usually warmer.



Density currents

Like any fluid, cooler water is usually denser than warmer water. When cold water near the poles encounters warmer water circulated from the equator, it sinks under the warmer water creating a deep cold current that may flow great distances.

In the oceans and seas, salt is also a factor in water density. Wherever there is high evaporation and little rain, the surface water becomes more salty and dense, and therefore sinks, to be replaced by new, less dense surface water from less arid areas. This circulation pattern is found in hot, dry areas like the eastern Mediterranean.

The Global Currents

Between the wind-driven surface currents and the deeper density currents, the oceans have both horizontal and vertical mixing, like the atmosphere.

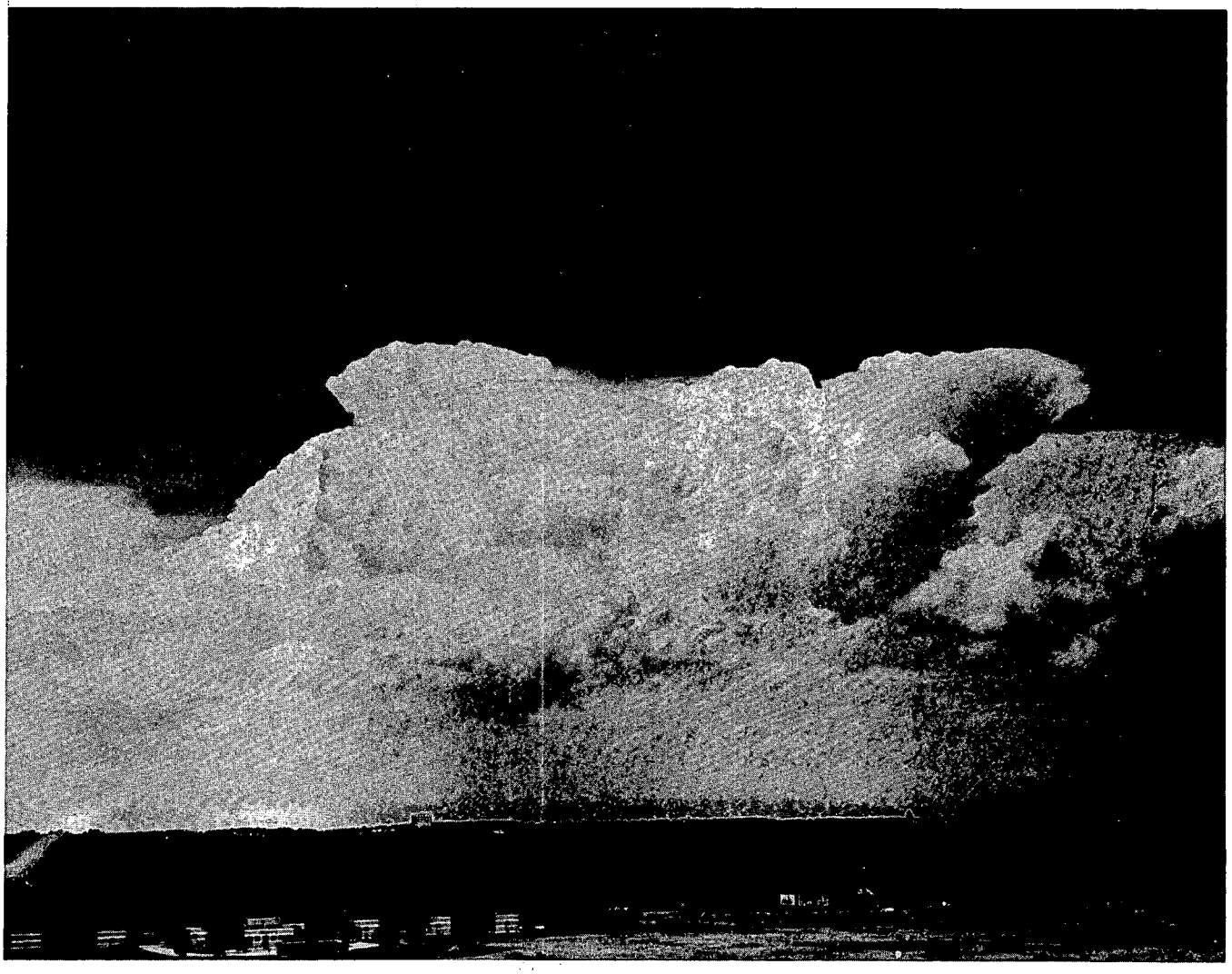
It is as hard to show the total picture of ocean circulation as it is to show atmospheric circulation. Putting together all the major factors, here is what we have:

- surface currents all over the earth reflect the patterns of the world's winds;
- the wind-driven surface currents curve in response to the Coriolis effect;
- the continental masses guide those curving currents into circular patterns; and
- deep currents are caused by dense (salty or cold) water flowing along the ocean bottom.

Again, the total effect is to move heated fluid to areas where it can give up its heat, and to move cold fluid to replace the heated fluid.

Interplay and Equilibrium

So many factors are involved in the global picture of wind and water circulation that the resulting patterns seem confusing and freakish. But however arbitrary they may seem, every movement of wind or water is part of a pattern. The result of that pattern is the transportation of solar energy through the total system, maintaining its ever-moving equilibrium.



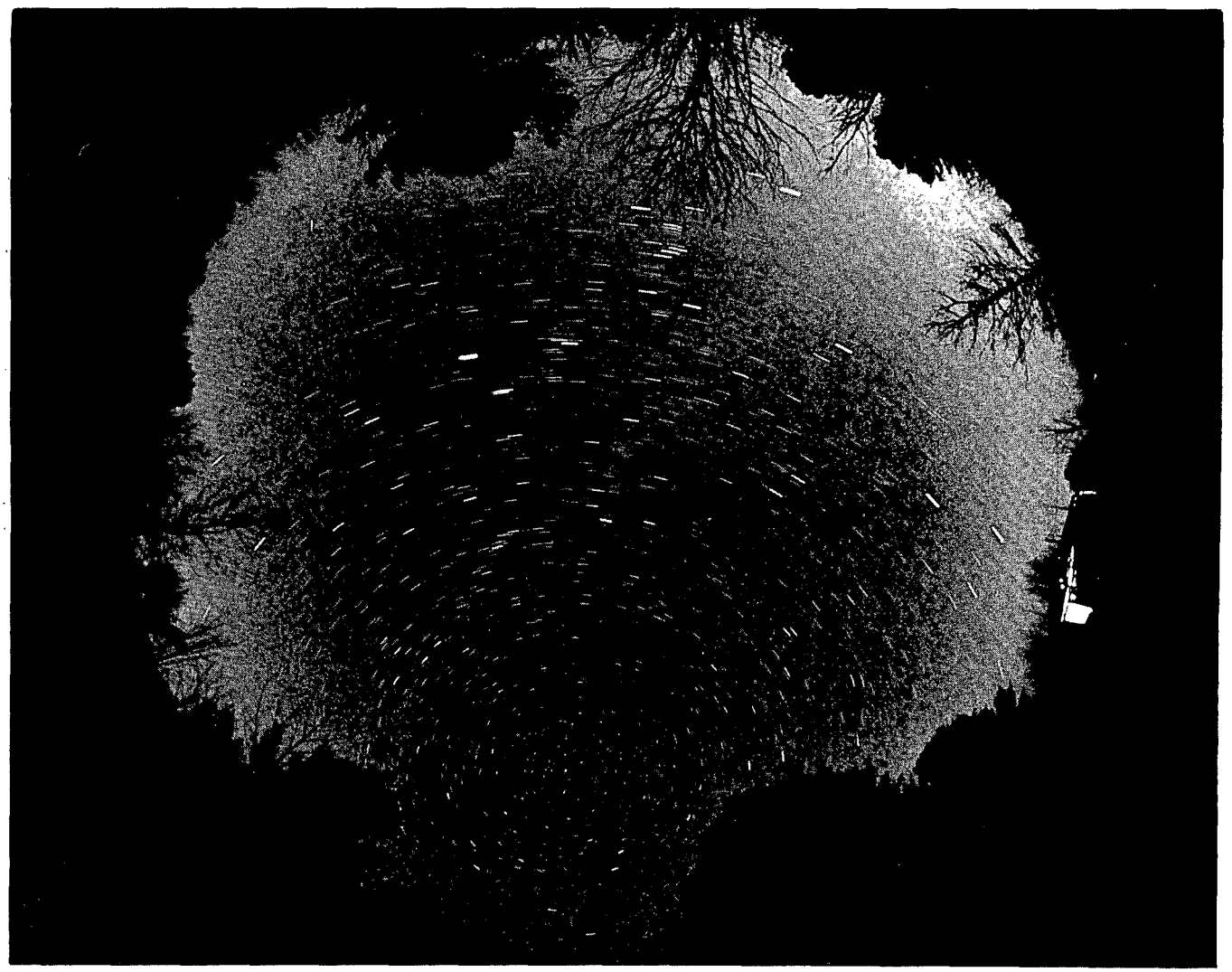
Vincent J. Schaefer

Chapter 8

A Home Issue

In our journey toward an understanding of the sun, it's as if we had left our bodies behind. We've traveled from the core of the sun to its surface and watched its display of fireworks. We've hovered in space and viewed the earth collecting the sun's rays. We've plunged through the earth's atmosphere and into its oceans to observe the effects of those rays on the earth's great circulatory system.

But we are not disembodied spirits. Each one of us is a person, living at a specific spot on earth. To use the sun's energy, we need to know what our personal solar budget is. Soon we will finish considering the macrocosm of sun and earth in space, and turn to the microcosm: your roof, my trees, the neighbor's greenhouse, the farmer's grain dryer, the needs of the local utility.



Keith Dayer

First, we need to see what factors determine how much energy arrives at our particular spot on the earth, and how we can measure and predict that energy. Solar radiation arriving at a given spot at a given rate is called insolation (not to be confused with insulation). The "solar constant" referred to in earlier chapters was measured on a surface perpendicular to the sun's rays and outside the earth's atmosphere. But when we measure insolation on the earth's surface, we have to remember that most of the earth's surface is not perpendicular to the incoming radiation, and that the atmosphere and other factors come into the picture.

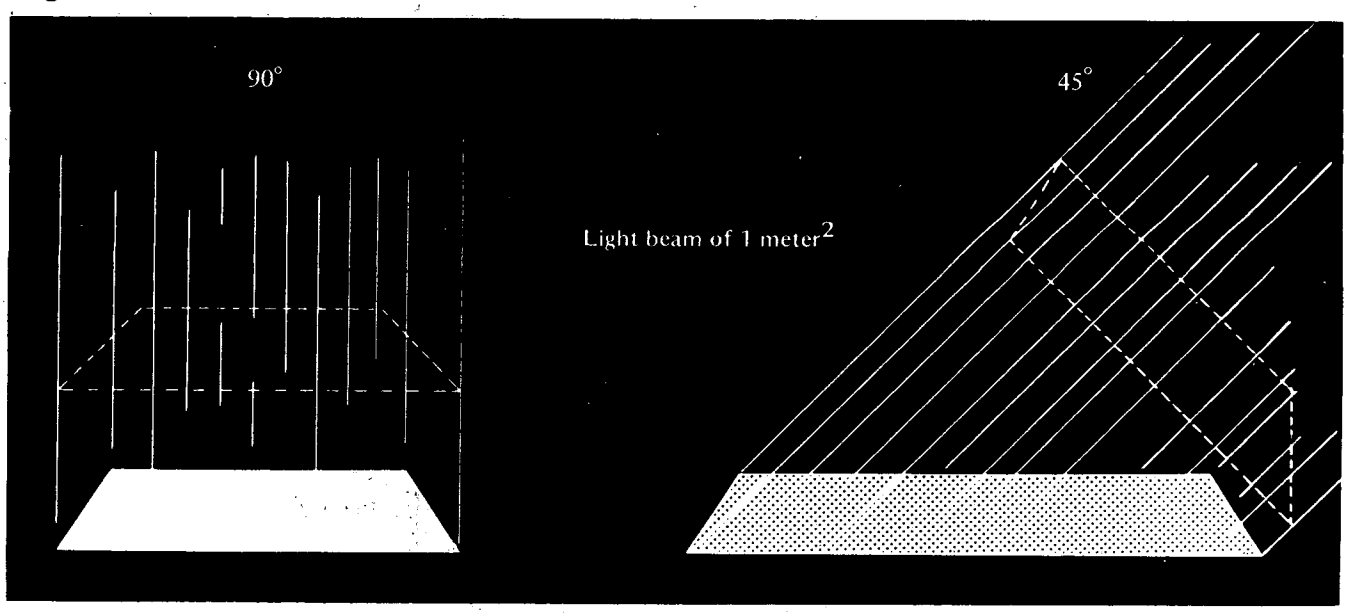
insolation: solar energy received at a given rate on a surface of a given size. (See glossary.)

Major Factors Affecting Insolation

Generally, two things determine the amount of radiation available per unit area of ground surface. One has already been discussed: the depletion of the solar beam by about one third by the atmosphere.

The other factor is the angle of the beam relative to the surface that it falls on. This is related to the shape of the earth and its daily rotations, and to the orientation of the earth during its yearly revolutions around the sun.

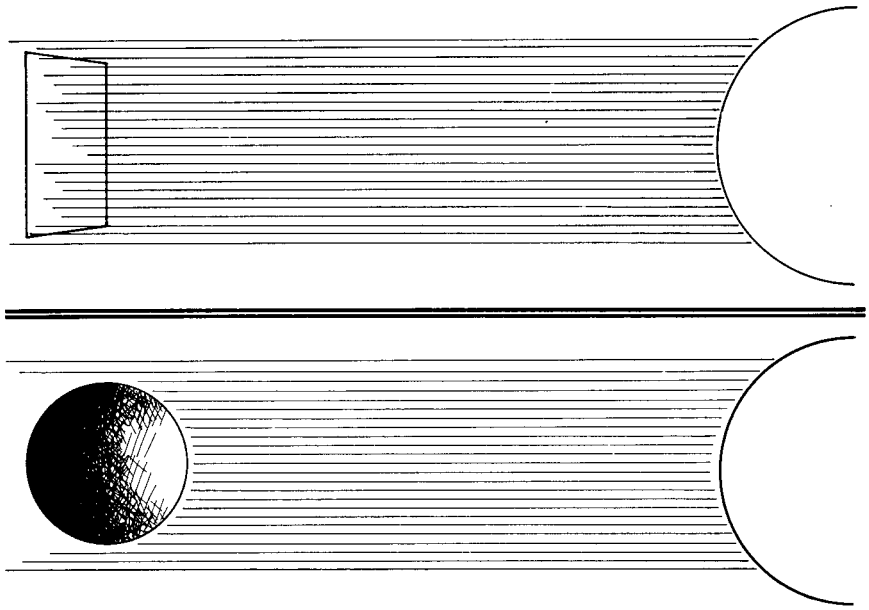
The effect of the angle can be seen very clearly from the diagram. If a solar beam one meter square falls perpendicularly on a flat surface, its energy is distributed over an area just one meter square. If the beam strikes the surface from a lower angle, its energy is spread over a larger area. The amount of energy per unit area decreases as the angle of the beam relative to the flat surface decreases.



The effect of beam angle

The Earth: a Rotating Sphere

If the earth and sun were flat and stationary, calculating beam angles would be simple. The angle would be the same for the whole flat earth, so the energy would be



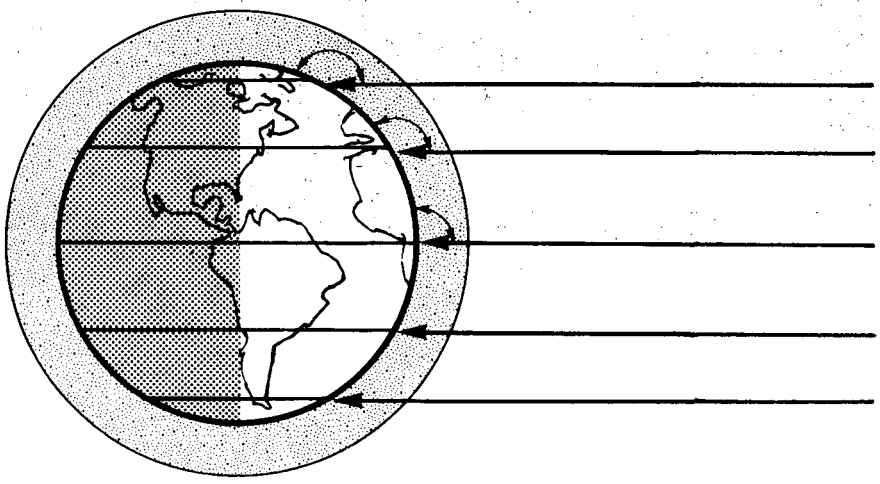
distributed equally on every unit area all the time. But the earth is a sphere, so the beam angle is different for different locations on the sphere. Also, the earth is rotating, so the beam angle is constantly changing for any given location on the rotating sphere.

What does that mean for your particular spot on the earth? That depends on where your spot is.

Latitude

Over the course of a year, the latitude of your spot on the earth is the greatest single factor determining how much insolation you'll receive. If you are located on the equator, you are receiving, on an annual average, the most possible insolation. This is because the equator is more nearly perpendicular to the sun's rays, on the average, than the rest of the earth.

The farther your spot is from the equator, the more slanting the sun's rays will tend to be, as you can see from the diagram. This means that the energy you receive per unit area will be less.

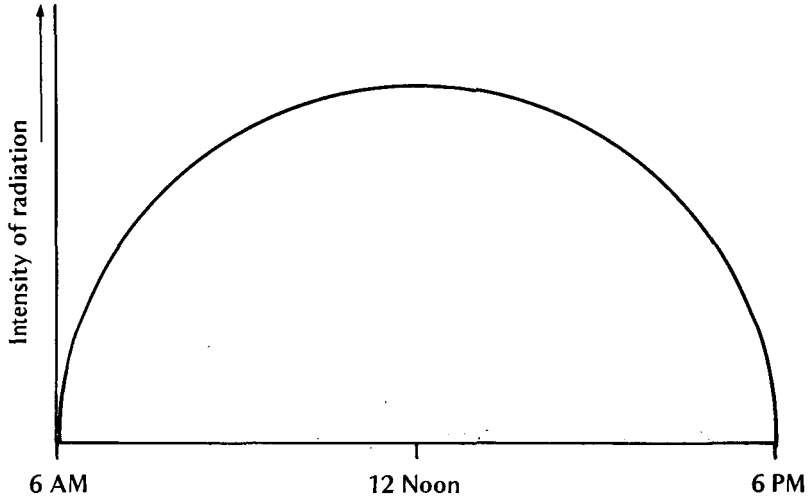


If you look carefully at the diagram you can see another factor reducing your insolation. Not only is the beam passing through the atmosphere, but at the higher latitudes the slanting beam must pass through more atmosphere. More atmosphere means more depletion of the solar beam. That's why we can look directly at the sun during sunrise and sunset: at such low angles the beam is so depleted that the little remaining energy doesn't hurt our eyes.

Not only does the thickness of atmosphere affect the amount of radiation; it also affects the kinds of radiation transmitted. When insolation arrives perpendicular to the earth's surface, it contains about 5% ultraviolet, 47% visible, and 48% infrared radiation. If the beam is low, however, say 10° above the horizon, the insolation received will contain only 0.5% ultraviolet and 41% visible, but 58.5% infrared radiation.

Time of Day

It follows that, just as your latitude on the sphere affects the amount of insolation you'll receive, so does the time of day. The graph shows clearly that the amount of insolation is linked to the time of day. By its resemblance to the path of the sun the graph reminds us that the greater the



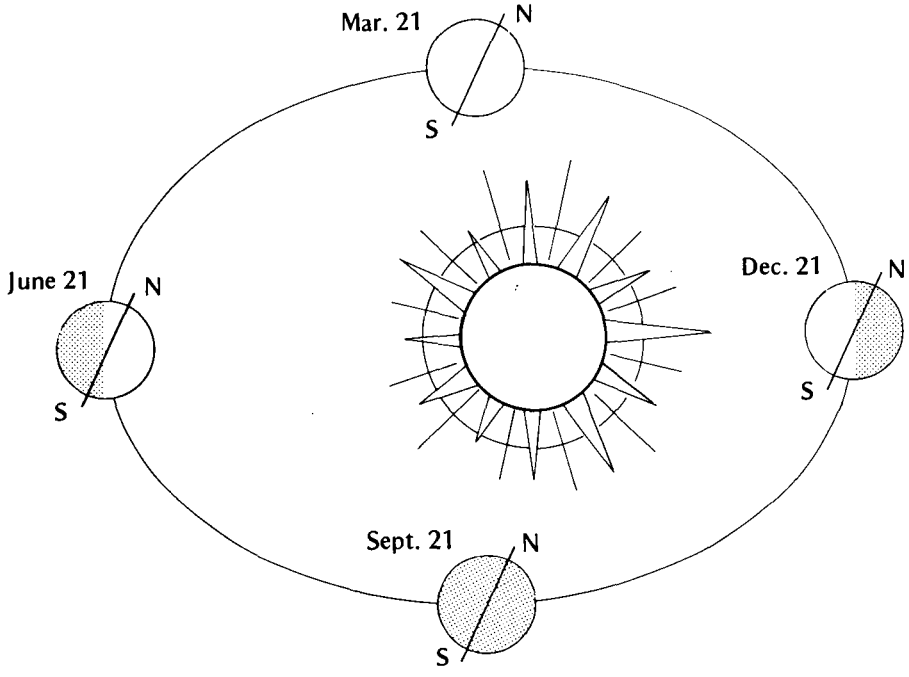
angle from the horizontal, (that is, the higher the sun in the sky) the more insolation is received per unit area. This graph should be taken to represent a day in March or September, when sunrise and sunset would occur at about 6 A.M. and 6 P.M.

The Earth: a Tilting Traveler

The earth, we have said, is a rotating sphere, and this means that our latitude and the time of day will affect how much insolation we receive. Furthermore, the rotating

sphere is tilted on the axis of its rotation, and, in that tilted posture, travels around the sun.

What this means is that in June the Northern Hemisphere, tilted toward the sun, receives more insolation than the Southern Hemisphere. Of course, in December the opposite is true. Because the tilt of the axis is 23½° from the perpendicular to its path, the angle of the sun's rays to your spot on earth varies by 47° from June 21 to December 21.



A minor factor is the fact that the earth's path is an ellipse. It happens that the earth is farthest from the sun in June and closest in December. But the change in distance is small; insolation in December, averaged over the entire earth, is about 6% higher than in June.

Other Factors Affecting Insolation

So far we have looked at the big, planetary features that affect the amount of insolation we receive at our particular spot on earth. There are also a number of local features, some temporary and some permanent, that play a part in your personal budget of sunshine.

Clouds

Cloud cover is the greatest day-to-day factor in variation of insolation. The earth has an average cloud cover of 50% of its surface, so you can see that clouds are a problem to be reckoned with in using the sun's energy. They vary in size, height, thickness, and type, and alter from moment to moment.

Clouds determine the amount of sunshine you receive out of the total possible for a given day. They also dictate whether the sunlight you receive will be direct or diffuse. You may have a completely but thinly clouded sky that is still admitting 95% of possible insolation in diffuse form all day long. On the other hand, a clear day with moving clouds may have many brief periods of direct sunlight, but other periods when "the sun goes behind a cloud" and 50% of possible insolation is lost.

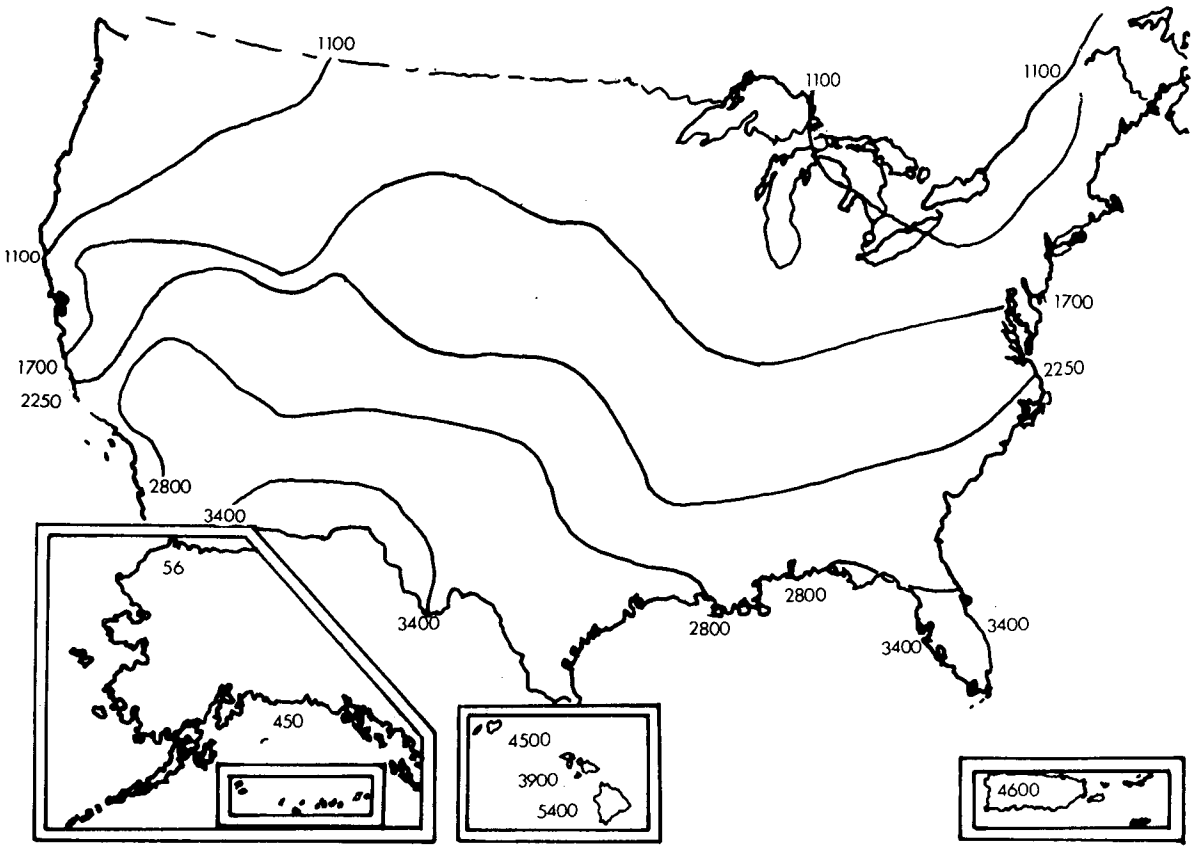
Vincent J. Schaefer

direct radiation: sunlight received directly from the sun's disk, without scattering or filtering. (See glossary.)

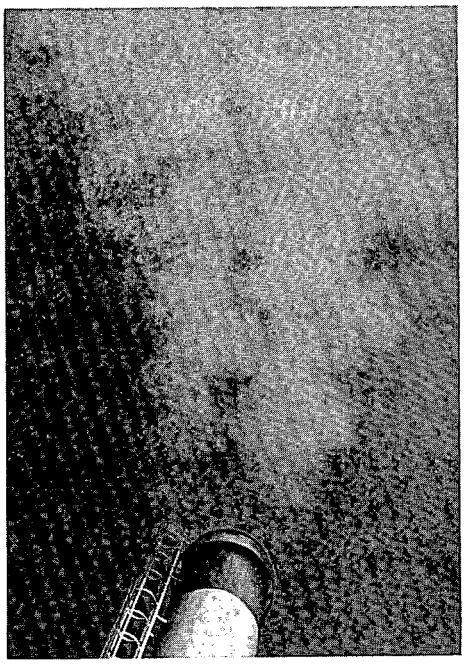
diffuse radiation: sunlight that is scattered by the atmosphere or filtered through clouds. (See glossary.)

New York State Department of Commerce

This variation in cloud cover causes large differences in daily and monthly insolation values for places at the same latitude. Fort Worth, Texas, for example, receives an average of 20% more insolation in the month of December than Griffin, Georgia, at nearly the same latitude. Ames, Iowa, and Medford, Oregon are both at about 42.5°N, but Ames receives 50% more insolation in December than Medford. Obviously clouds are a major factor in the solar budget.



Mean daily solar radiation for December, in watts/meter^2



SUNY Atmospheric Sciences Research Center

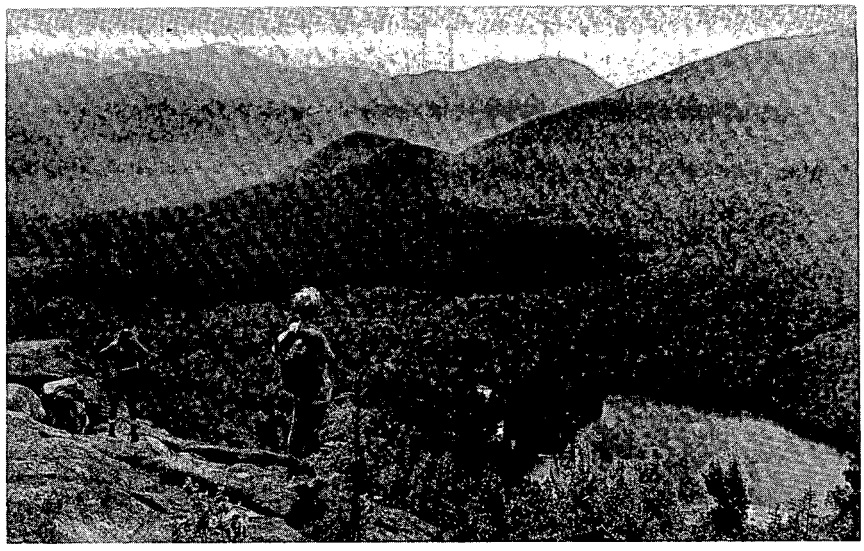
molecule: a grouping of atoms; the smallest unit of an element or compound which retains the chemical properties of that element or compound.

Atmospheric Turbidity

"Turbidity" means a reduction in transparency of the atmosphere caused by particles which scatter or absorb visible light. Haze, smoke, fog, smog, dust, ash, etc., all contribute to atmospheric turbidity. So if you live near an active volcano, in a smoky factory town, among heavily traveled urban streets, or in some other "turbid" area, your budget of insolation may be reduced. Pollution around large cities can decrease insolation by as much as 20%. Also, turbidity alters the proportions of ultraviolet, visible, and infrared radiation received. The percentage of ultraviolet and visible radiation received decreases, and the percentage of infrared increases.

Altitude

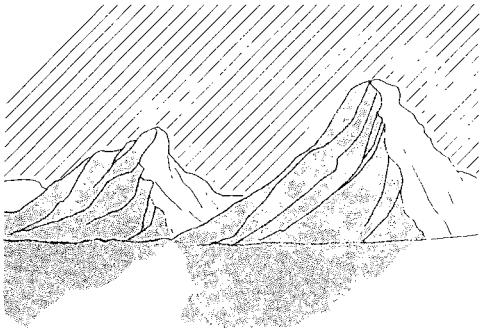
Altitude is another factor in your insolation budget. Why do climbers in the Alps and the Himalayas have to guard against sunburn? Increased altitude means decreased density of atmospheric molecules, which means less absorption and scattering of the incoming solar beam. At higher altitudes, then, the solar beam contains more energy, particularly in the ultraviolet range.



New York State Department of Commerce

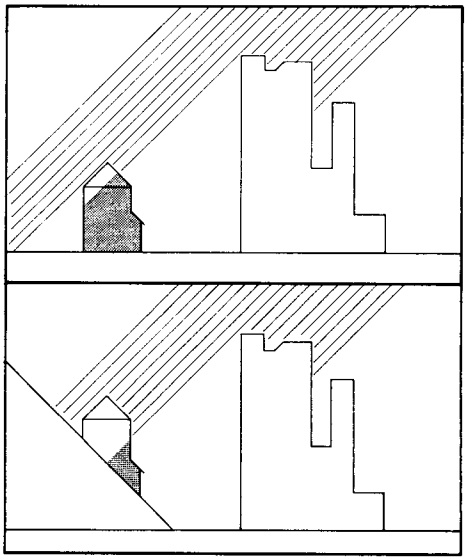
Land Surface Features

Hills, mountains, and the general "lay of the land" can determine the insolation received at your spot on earth. If your horizon is a ring of hills or mountains, you may actually have a shortened period of daylight, and, therefore, less insolation.



In addition, the slope of your property may increase or decrease your energy reception. In the northern hemisphere, where the sun is generally in the southern sky, land that slopes down toward the south has the advantage of being more perpendicular to the sun's rays. It, therefore, collects more energy per unit area than flat or north-sloping land. (You'll notice in the spring that snow melts first on south-facing slopes.)

Obstructions

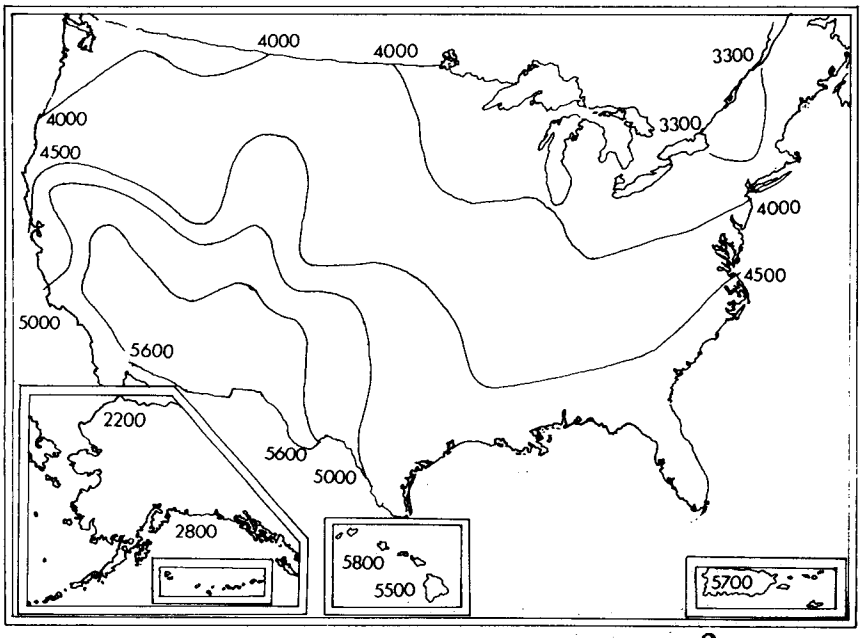


Objects that block the sunlight are becoming the subject of an interesting legal debate. Do you have a right to build between your neighbor and the sun? Can you compel your neighbor to remove a tree that shades your house? Obstructions can significantly reduce your insolation budget, especially if you live in an area of dense population. (By the way, another advantage of a south-facing slope is that obstructions to sunlight are "down the hill" from you and less likely to be a major block to solar radiation.)

The Nation's Solar Budget

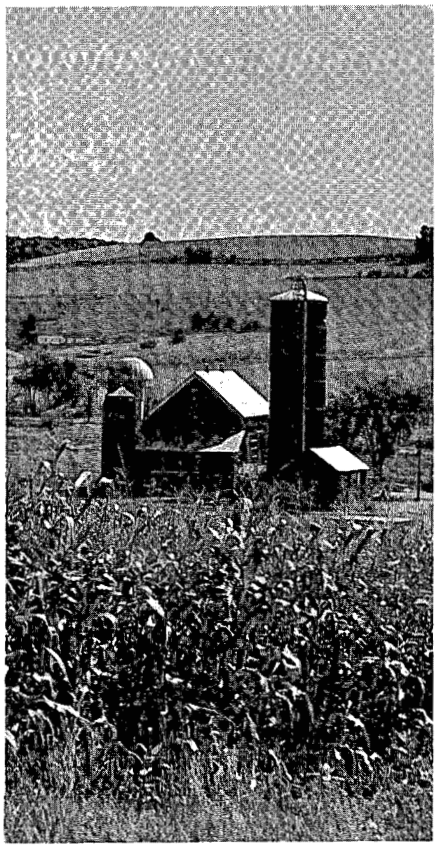
All the factors discussed in this chapter have some effect on insolation, with latitude and cloud cover being the most important. The result is that different regions of the country have different annual insolation averages.

The northeastern states and the Pacific Northwest share the unenviable status of being the cloudiest parts of the nation. On an annual average they receive only 3/5 of the amount of insolation received by the Southwest, which is the sunniest part of the country. The map gives an idea of who gets how much sunshine per year, although it leaves a lot of questions unanswered.



Annual average solar radiation in watts/meter^2 (averaged over the full year, day and night)

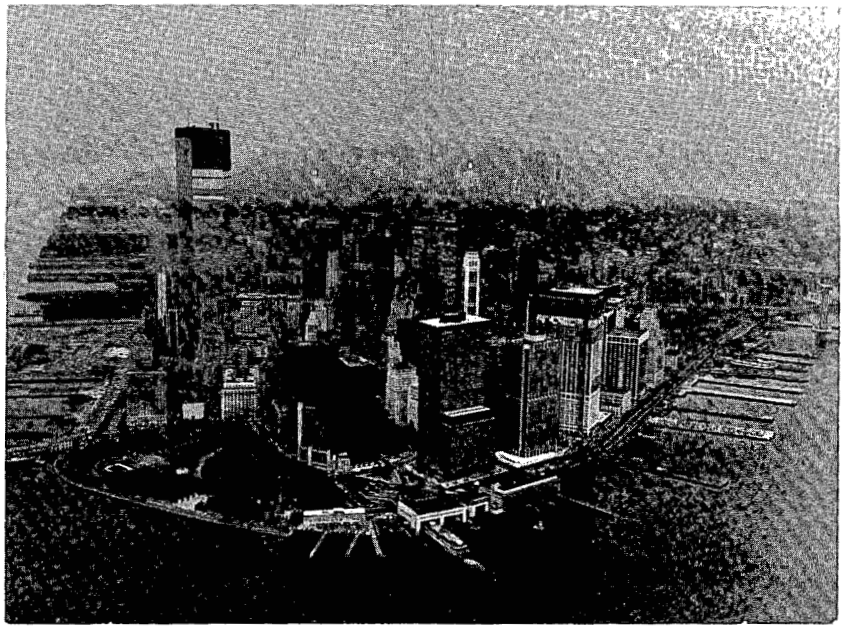
One of the unanswered questions is: How does insolation vary within states and localities? In the state of New York, for example, the mean daily solar radiation on a horizontal surface (both direct and diffuse radiation) is about 150 watts per square meter. But central and eastern Long Island in the southern part of the state do better than that, averaging 158 watts/m^2, while the mountainous Adirondack area in northern New York receives only 142. Lake Erie and Lake Ontario are the source of lake-effect cloudiness which



reduces insolation in the late fall and winter for the western and central parts of the state, and sometimes even the eastern section. We can see, then, that there can be quite a bit of variation within states and regions.

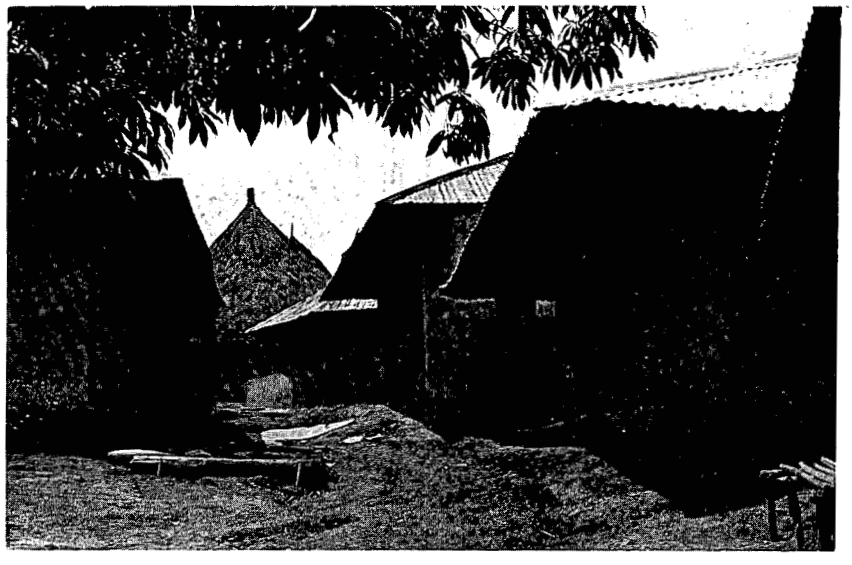
Your Personal Solar Budget

The conclusion you should draw from all the preceding information is that a person's solar budget is a highly individualized thing. It depends on your latitude and annual weather patterns, but it also depends on the air quality of your area, the structures and trees around your location, and even the slope of the land. Every location is different, so individuals need to take their own measurements and make their own assessments. After seeing how these measurements can be made, we will look in later chapters at the variety of ways solar energy can be used.



New York State Department of Commerce

New York State Department of Commerce
Vincent J. Schaefer

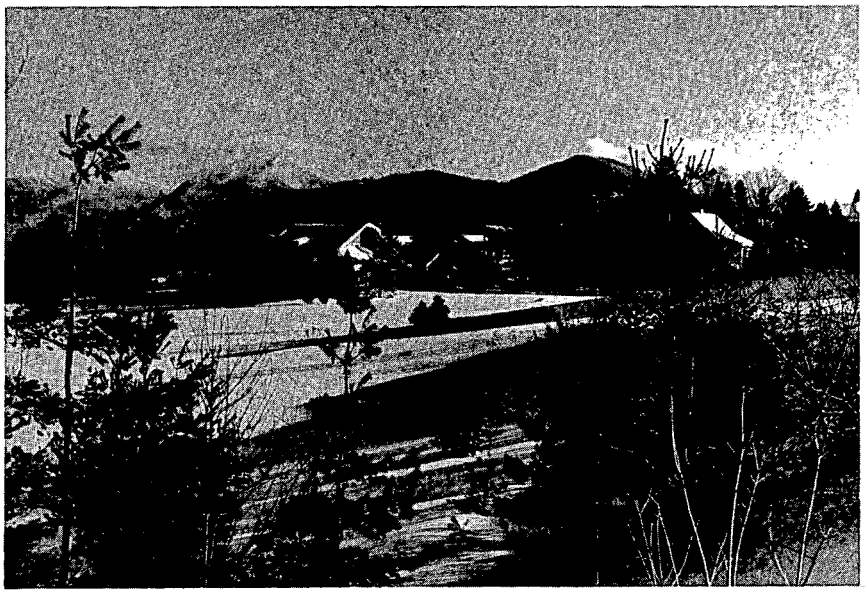


Donald Hegeman

Chapter 9

Metering the Sun

Our study of the sun is gradually becoming more personal. We are homing in on specific locations, our own locations. It's fine to know how much energy the sun produces, but what each of us really wants to know is: "What about me? How much solar energy do I get? Is it enough to be useful to me, at my little spot on earth?"



N.Y.S. Department of Commerce

Vincent J. Schaefer

People have been measuring insolation and keeping records of those measurements for some time. But insolation has several forms, and there are several ways of measuring

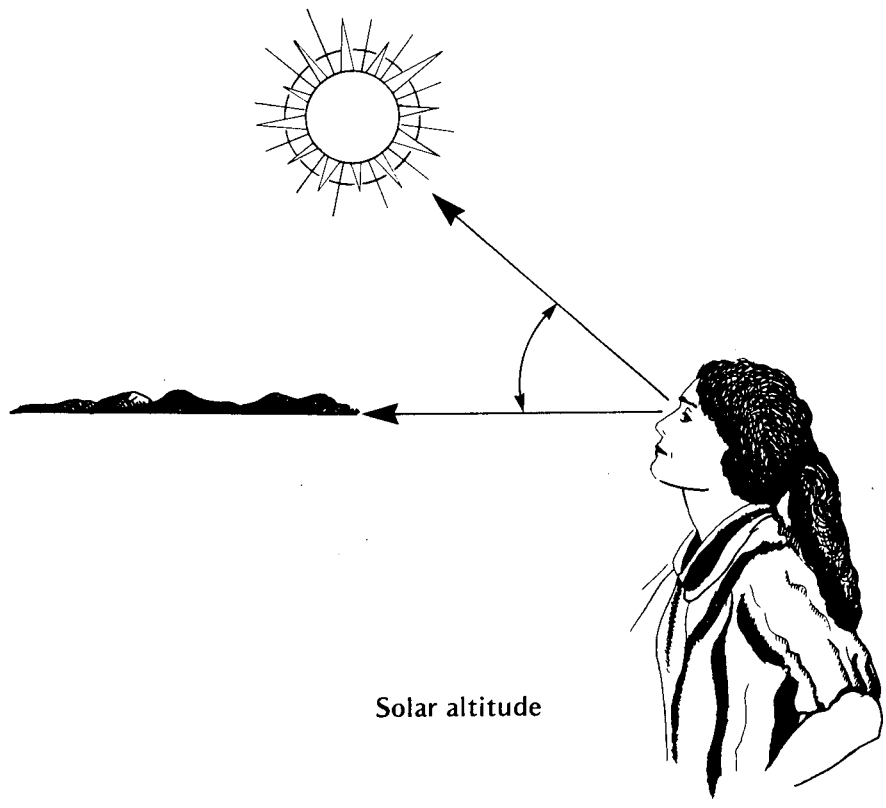
insolation: solar energy received at a given rate on a surface of a given size. (See glossary.)

it. What measurements are useful to you will depend on how you plan to use solar energy. Some types of solar collectors take advantage of both direct and diffuse radiation; others can only use direct radiation. If there are trees or other buildings around your location, you need to know the altitude and azimuth of the sun to find out if your location gets enough sunlight. This chapter will discuss how sunlight is measured and where you can obtain the needed measurements.

(Later chapters will discuss wind and hydropower and describe how those indirect forms of solar energy can be measured.)

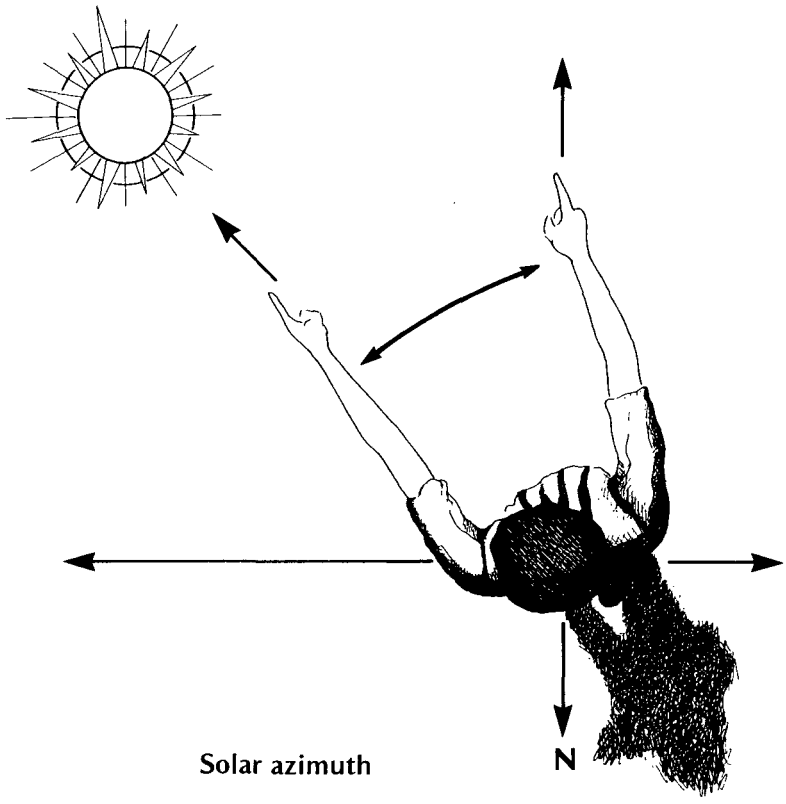
Let's define some terms. Direct radiation is the insolation that has traveled a straight path from the sun's visible disk. Direct radiation is bright and causes shadows. But there is also a great deal of radiation that is scattered by the atmosphere or filtered through clouds, and is received by us in the form of diffuse radiation from the sky. This diffuse radiation is not bright enough to cast shadows, but it gives considerable insolation; otherwise, we'd need flashlights on a cloudy day. Direct and diffuse radiation together give us global radiation, the total radiation received from both the sun's disk and the sky.

Besides being able to measure amounts of sunlight, you need to be able to measure the sun's location and path in the sky. Two terms used in making these measurements are altitude and azimuth. The sun's altitude shows its height in the sky. It is the angle between a line pointing at the sun and a line pointing at the horizon directly below the sun. The



Solar altitude

sun's azimuth shows its distance from true south (or north, in the Southern Hemisphere). It is the angle between a line pointing south and a line pointing at the horizon directly below the sun.



Solar azimuth

Measuring and Charting Solar Energy

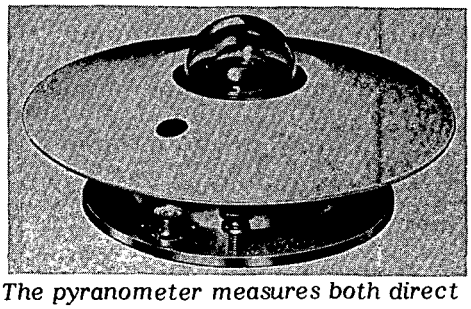
We'll begin by seeing how amounts of insolation are measured, and then see how the sun's location and path are charted.

Measuring Insolation

Meteorologists have been measuring insolation for a number of years, and have developed a variety of devices for doing so.

meteorologist: a scientist who studies the atmosphere and its phenomena.

The pyranometer measures global radiation. Usually mounted horizontally, it consists of whitened metal plates and blackened metal plates connected by thermocouples. (A thermocouple is two dissimilar metals, like copper and Constantan, with a wired connection between them. Its purpose is to measure the flow of electrons proportional to temperature differences.) The white areas reflect radiation, but the black areas absorb it and become heated, producing a small electric current in the thermocouple. The current thus generated can be measured to show the amount of radiation received. The sensor area is usually covered with a glass hemisphere. The pyranometer (also called a solarimeter) is sensitive to radiation wavelengths from approximately 0.29 micrometers to 3.0 micrometers, which include most of the energy received from the sun.



The Eppley Laboratory, Inc.

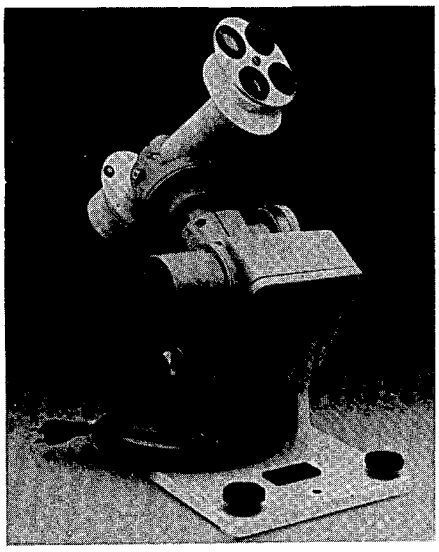
The pyranometer measures both direct and diffuse radiation.

The pyranometer described above takes several seconds to respond. A pyranometer made with a silicon cell responds much more quickly, in less than a millisecond. However, it has a more limited response range, from about 0.4 micrometers to about 1.1 micrometers, with its maximum sensitivity at around 0.65 micrometers. This is good for visible sunlight, but leaves out a good deal of the longer wavelength solar radiation that we receive.

A pyranometer can even be used to measure the amount you are receiving of a particular wavelength of radiation. This is done by placing selective filters over the pyranometer.

If you wanted to measure only diffuse radiation without counting direct radiation you would use a shaded pyranometer. This is a pyranometer with a disk mounted over it that moves with the sun, blocking direct radiation. Since it is difficult to keep the shading disk in perfect adjustment, some prefer to use a shadow ring which replicates the sun's path. The price you pay for using the shadow ring is that some of the diffuse radiation is cut off from the sensor by the ring, and you must correct your calculation for that loss. The ring must also be adjusted as the sun's altitude changes with the seasons.

Suppose that you want to measure only direct radiation from the disk of the sun, excluding all diffuse radiation. To do this you'll use a pyrheliometer. This device has sun sensors mounted at the bottom of a blackened tube, whose length is about ten times its diameter. This limits the view of the sky to about 5°, and eliminates most diffuse radiation. To measure direct radiation over a period of time, the pyrheliometer must track the sun. You can mount it on a motor-driven device timed to follow the sun's movements; such a device is called a heliostat. Daily or weekly adjustments must be made as the sun's altitude in the sky changes with the seasons.



The Eppley Laboratory, Inc.

The tube design of the pyrheliometer excludes most diffuse radiation, allowing the instrument to measure just direct radiation from the disk of the sun.

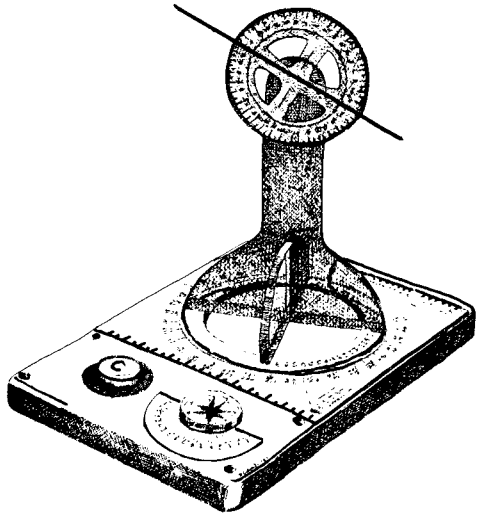
The instruments discussed here usually measure solar radiation as current generated in thermocouples. There are still other methods for measuring radiation: for example, heating water or vaporizing alcohol, burning a line on a strip chart with a focussing lens, or photochemical reactions.

Measurement of solar radiation is done by the National Weather Service at a number of stations around the country, and compiled by the National Climatic Center in Asheville, North Carolina. Various colleges and research centers also compile solar data, and many radio stations are beginning to broadcast a daily "Solar Index" as part of their weather report.

As interest in solar energy grows, so does the need for comprehensive solar data.

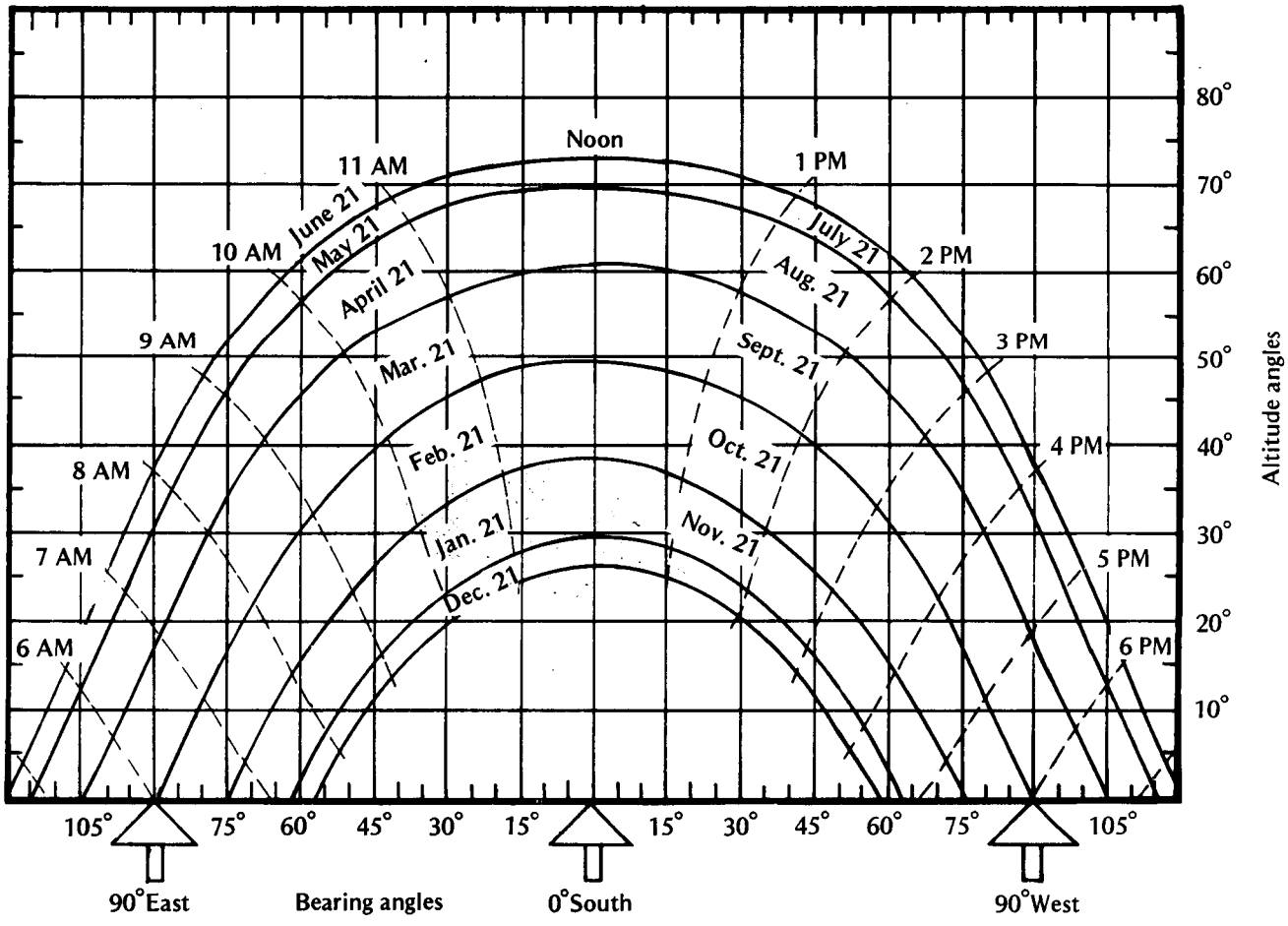
Charting the Sun's Path

Besides knowing how much radiation you are receiving, you need to know where and when you are receiving it. The answers to these questions will tell whether your location, with its orientation and surrounding obstructions, gets enough radiation at the right times for you to use.



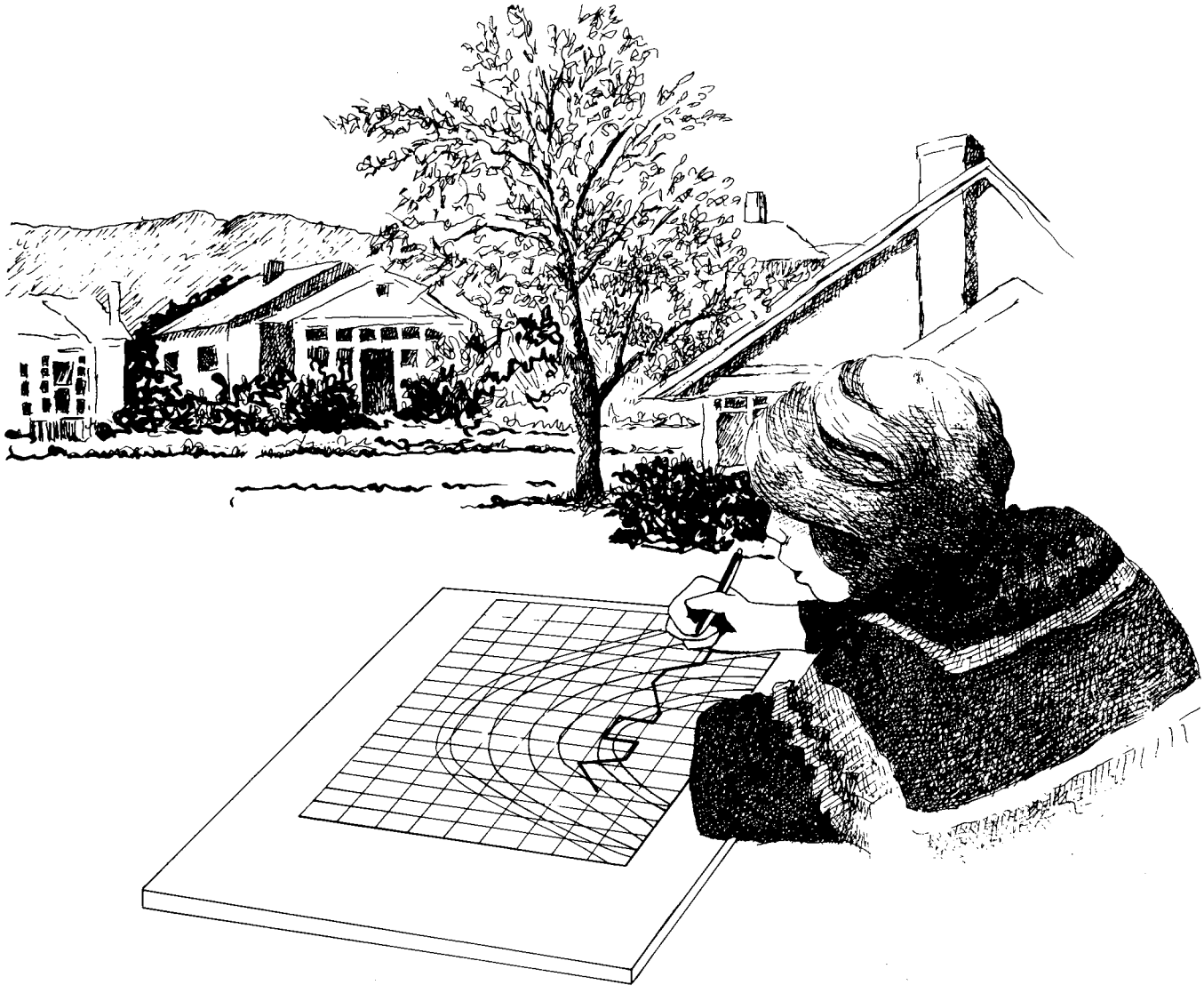
To find these important answers many people today are using sun siters or sun charts. A sun siter is simply a transit, an instrument used to measure vertical or horizontal angles. The transit is mounted on a board in which are set a bubble level and a compass. The level allows you to locate the true horizon, and the compass orients you north-south. You can then chart the altitude and the azimuth of the sun at different times of the day and year.

The chart that results from these observations is a sun chart for your latitude and longitude. These charts are available commercially as well, or can be found in books on astronomy and solar energy. Using a sun chart you can check to see where the sun will be rising and setting at your location, how high it will be in the sky, which side of your house or building will get the most sunshine, and to what extent the obstructions surrounding your location will cut into your solar budget. Several books that contain sun charts are listed at the end of this chapter.



Sun chart for 40°NL

As you become interested in using solar energy, it will be important for you to know how to measure the energy potential of your location. The same thing could be said of wind energy or hydropower, which are secondary forms of solar energy. You must find out how much sunshine, wind, or falling water you have at your site before you can decide on how to use them. Any energy system requires an investment to get started with. Before you make that investment, be sure that you have enough fuel to run the system. You wouldn't put in a new oil furnace if you knew that your supply of oil would soon be cut off. The supply of sun, wind, and water are always there, but how you use them must depend on their availability, and the convenience and cost of using them at your spot on earth.



Chapter 10

Understanding the Solar Solution

In a world plagued by shortages and crises solar energy is very attractive. Even without much knowledge of how it works, many people regard it as safer, cleaner, and more reliable than other forms of energy. Some people even regard solar energy as somehow more righteous, independent, and filled with integrity than other energy resources.

A Web of Problems

Much of this feeling has grown from the painful dilemmas of the last few decades. As the world's peoples grow more sophisticated, more intertwined, and more numerous,

R.A. Fogarty

problems that once seemed separate and manageable have suddenly formed an enormous and ever-tightening web. Each solution seems to pose another problem: more productive crop strains require more petroleum-based fertilizers and encourage more population growth to devour the new crops; some fuels may pollute the atmosphere, changing the earth's temperature and shifting the agricultural balance; international trade improves the standard of living but introduces political pressures and dependencies across borders.

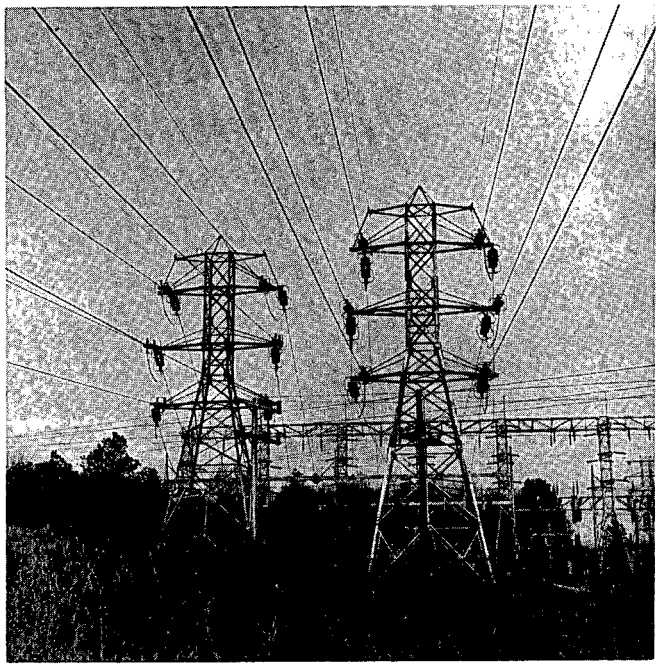
At the center of this web of problems is energy, the basis of all movement and life on the planet. Problems of energy seem linked to every other problem in this global web. No wonder people long for a more rational solution to believe in. For many, solar energy seems to offer that solution.

Being Selective about Solutions

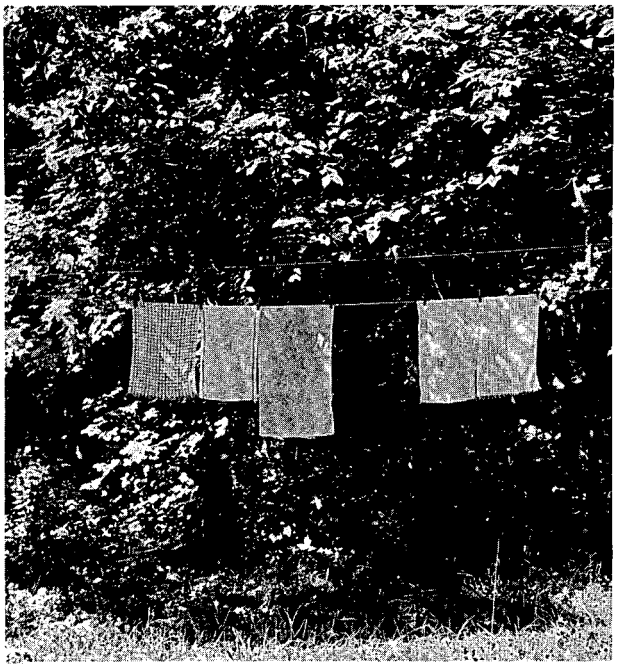
No amount of belief will substitute for knowledge, however. The reality of solar and related forms of energy technology is that they are regional and local in application. From the simplest and most personal to the largest and most complex, how well they will work depends on who uses them, where they are used, and what they are used for. What works for your cousin in Seattle or your friend in Atlanta may not work for you. What fits one industry may not fit another. The key word is "appropriate". An appropriate technology is one that is wisely tailored to use the type and level of energy most appropriate for the job, whatever that job may be.

appropriate technology: technology which is suited to its end use.

This standard of appropriateness should make us take a long look at some of the forms of energy that take years, even millions of years, to produce. Does it really make sense to burn oil or use nuclear fuel to generate electricity to send over hundreds of miles of wire to heat a room on a sunny day? Is it really necessary to burn gas to dry clothes on a



Edward Lalor



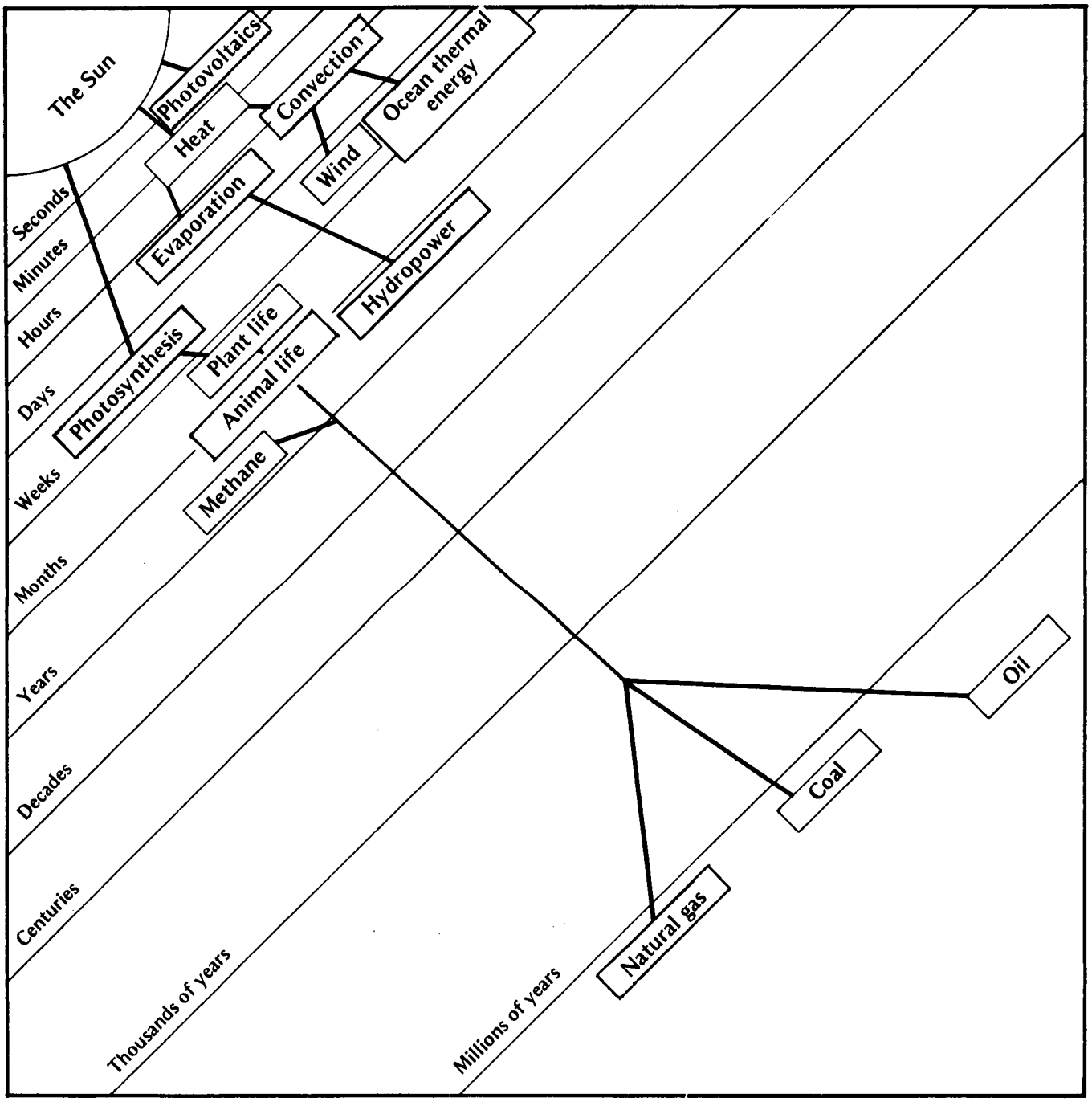
R.A. Fogarty

windy morning? If an industry needs steam at 155°C, must the 10°C ground water be heated entirely with fossil fuels to reach the needed end temperature? Oil, coal, gas, and electricity are crucial for certain types of work. Why squander them unnecessarily?

An Energy Time Line

Take a glance at where our energy comes from and how long it takes to reach a usable form. The sun can produce electric current in a photovoltaic cell in a fraction of a second. It can heat air, water, or other materials in a matter of minutes, setting up movements in the atmosphere and the oceans that give us secondary forms of solar energy (wind and

photovoltaic cell: a device that converts radiation directly into electric current. (See glossary.)



ocean thermal gradients: temperature differences between warm surface water and cold deep water which can be used to generate electricity. (See "ocean thermal energy conversion": glossary.)

ocean thermal gradients) in a short time. The direct heat of the sun fuels the cycle of evaporation that, over a season or a year, refills our streams, ponds, lakes, and rivers to give us hydropower.

Photosynthesis, which stores solar energy as food and fuel, requires weeks or, with trees, years. But its time cycle is still on a scale with the human life span. Methane gas, a product of decaying plant and animal matter, is a second or third-hand form of solar energy. With the help of bacteria, methane can be generated rather quickly, over a period of months. But as it occurs in nature, as natural gas, it requires a drastically longer time.

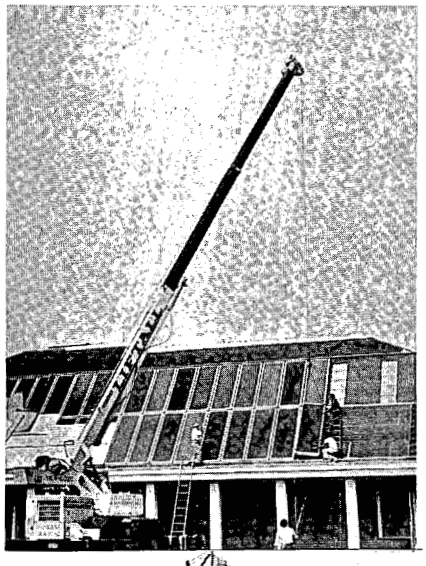
With natural gas we arrive at the most distant forms of solar energy, distant in relationship but, more especially, distant in time. To the days and seasons required to produce solar heat, winds, ocean currents, plant and tree growth, compare the millions of years required to produce natural gas, coal, and oil. To say that we have consumed in decades what it took centuries to make is no exaggeration; in fact, it is an understatement. The gas, coal, and oil deposits of the earth took millions of years to produce. Estimates of the remaining supplies vary. What is clear is that at our present rate of consumption, all the cheaply and easily reached supplies of these fuels will be exhausted in the next few decades. If all the fossil fuels have gone up the chimney, where will we turn for the chemicals, plastics, and pharmaceuticals they could have been saved for?

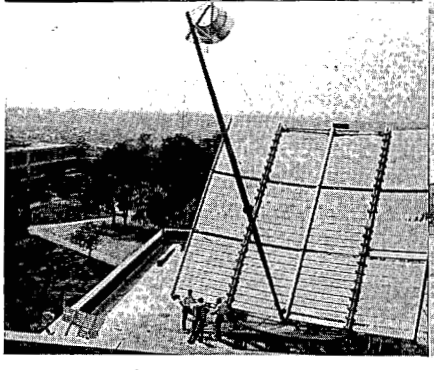
It is this growing question that has led people to turn to the sun for a solution, and to begin acquiring the knowledge they need to work out that solution.

Applications of Solar Energy

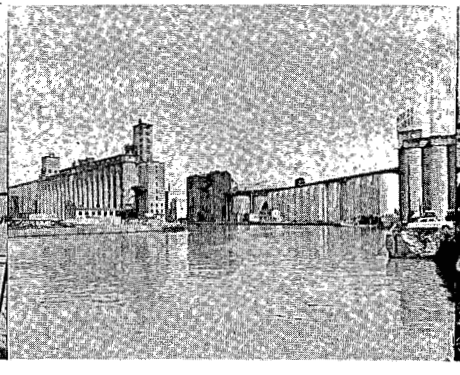
What options does the sun offer? They are many and varied. Here is a basic list of things the sun can do for people:

- heat (or cool) homes, schools, and workplaces;
- heat water for domestic or industrial use;
- dry crops;
- desalinate water;
- produce food by aquaculture or agriculture;
- grow wood and other fuels for burning;

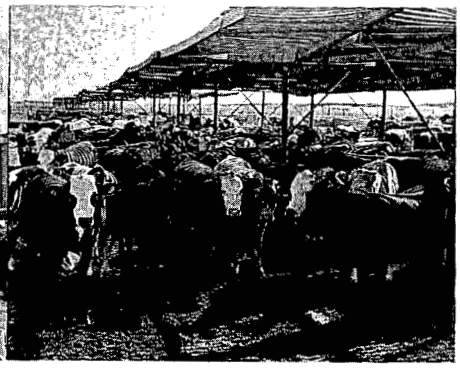




Grumman Energy Systems, Inc.
Rensselaer Polytechnic Institute

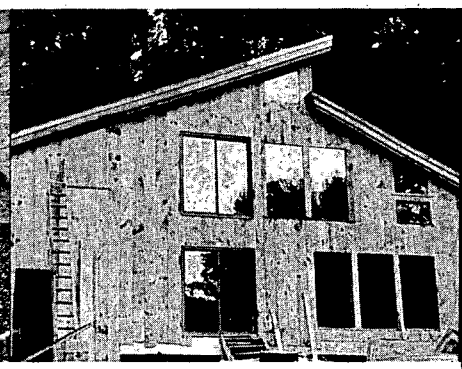


New York State Department of Commerce

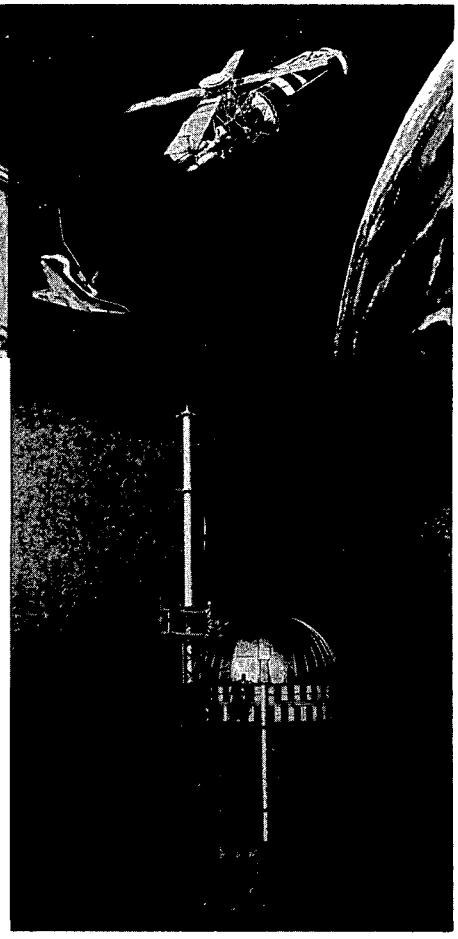


Pacific Gas and Electric

Donald Hegeman



Adirondack Alternate Energy

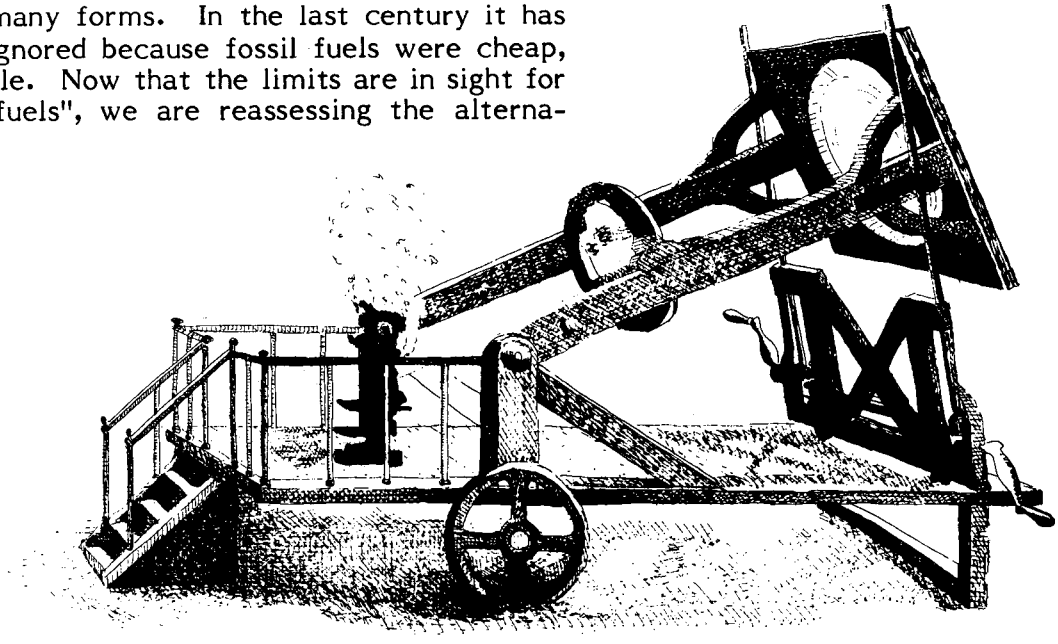


National Aeronautics and Space Administration
Clarkson College

- yield substitutes for natural gas and gasoline;
- generate electricity by means of photo cells, wind, hydropower, ocean thermal gradients, or focussing of radiation;
- cook foods and dry clothes;
- preheat, melt and/or vaporize materials.

None of these functions is new. All have been undergoing experimentation for years, and some have been known and used for centuries. The early inhabitants of the American Southwest understood solar heating, and the people of Persia were using effective windmills as long ago as the seventh century. For thousands of years, ancient people relied on the sun's energy to evaporate small pools of brackish water so that they might collect the salt. In 1872, a large solar still was built in the Chilean desert to supply 6000 gallons of pure water per day from salt water. Solar cookers were built and used in India in the 1880's. Michael Faraday discovered the principle of solar cooling in 1824. Small steam engines were powered by solar energy as early as 1878; a 50-horsepower solar engine was used in 1913 to pump irrigation water in Egypt. Solar hot water heaters were popular in our southern and western states in the 1930's.

So throughout history, people have been familiar with solar energy in its many forms. In the last century it has been overlooked or ignored because fossil fuels were cheap, plentiful, and versatile. Now that the limits are in sight for those "convenience fuels", we are reassessing the alternatives.



Taking a Long Hard Look

It is important to be realistic in making our assessment. First, the form of energy used must be appropriate to the task to be done and to the location. Second, we must be prepared for the likelihood that one form of energy may not be the whole solution. The owner of a solar heated home will probably want a wood stove or gas furnace as a "back-up." A factory owner may find that he can cut his fuel bills in half by preheating his process water in solar collectors, but that to bring the water up to the full temperature needed he must sometimes turn to his conventional fuel source. The nation's demand for electricity may have to be met from a number of sources, both new and conventional; hydropower, solar power towers, photovoltaics, and wind can gradually play an increasing role in electricity production.

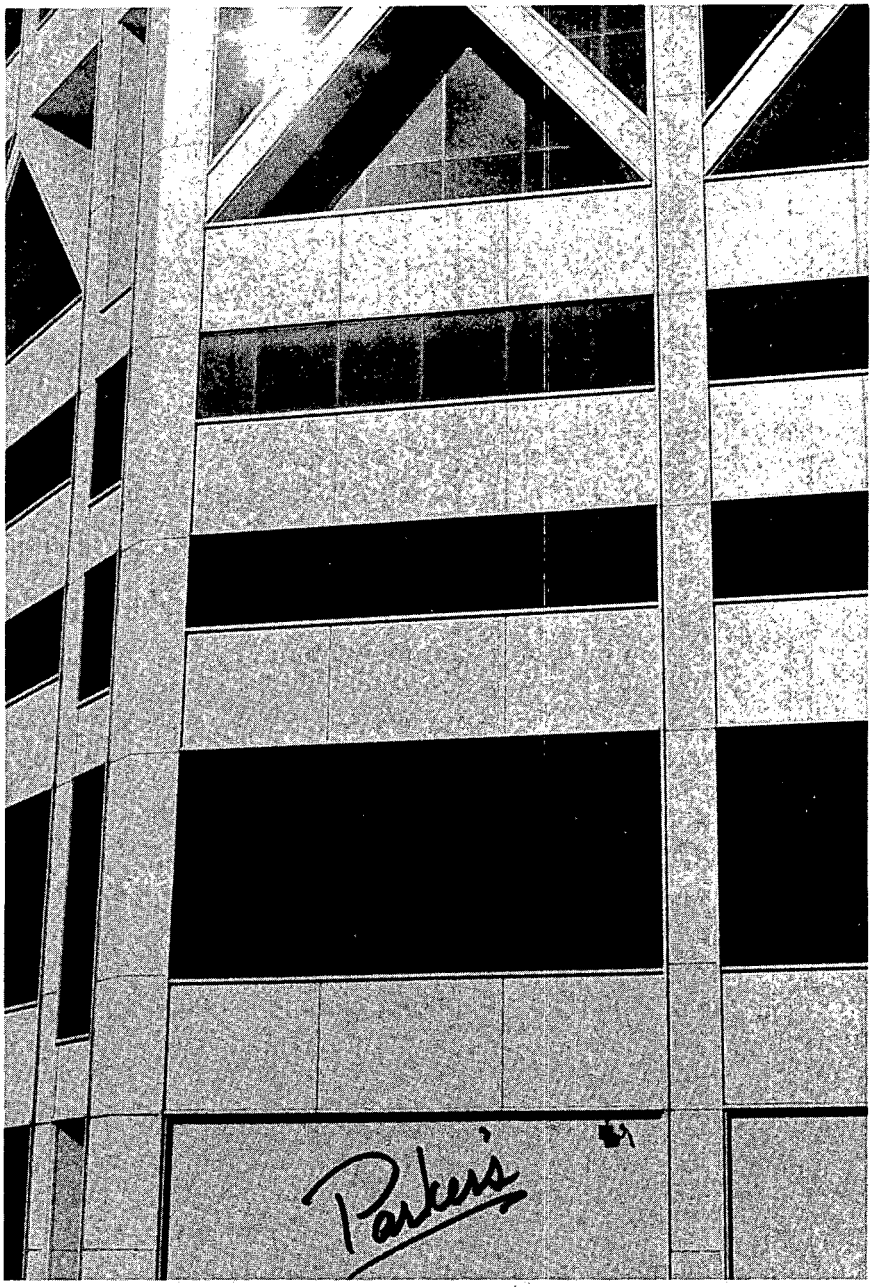
solar power tower: a large installation with tracking mirrors which focus sunlight on a boiler to produce steam for generating electricity. (See glossary.)

Finally, energy conservation must be the basis of all appropriate technologies. Solar energy by its very nature is not centralized or concentrated. It is dispersed, and arrives intermittently. It requires know-how to make the most of it, to save and store what is collected. Plans for using solar energy in any of its forms must rest on a foundation of conservation knowledge.

In our effort to break through the web of problems that enmeshes us, we have a potent ally and friend, the sun. Can it be, as people hope and believe, a source of reliable, safe, and clean energy? Yes, if we understand it thoroughly and know how to use it.

Chapter 11

Living Space That's Solar



R. A. Fogarty

In learning about the uses of solar energy, the most natural starting point is the study of living space. More than twenty percent of our national energy budget goes to heat and cool the places people live in: homes, offices, stores, factories, and schools. So let's start with actual buildings and see how they can be designed to collect, circulate, and store solar energy.

What we're talking about is called passive solar design. With passive solar design, there is no added-on machinery or device; the structure itself is the solar collector. It just sits there "passively," absorbing solar radiation through the day and conserving it through the night. Conservation of energy is, in fact, so important to passive solar design that it will be covered in a separate chapter. The present chapter will concentrate on one subject: how a structure can be designed to collect, circulate, and store solar energy.

The Elements of Passive Solar Design

Every structure collects solar energy, whether we intend it to or not. Sunlight coming in a south window heats the objects and surfaces inside. A dark roof absorbs radiation and the attic becomes warm. Deciduous trees shade the house during the summer. These are things that we take for granted, that are so familiar as to go unnoticed.

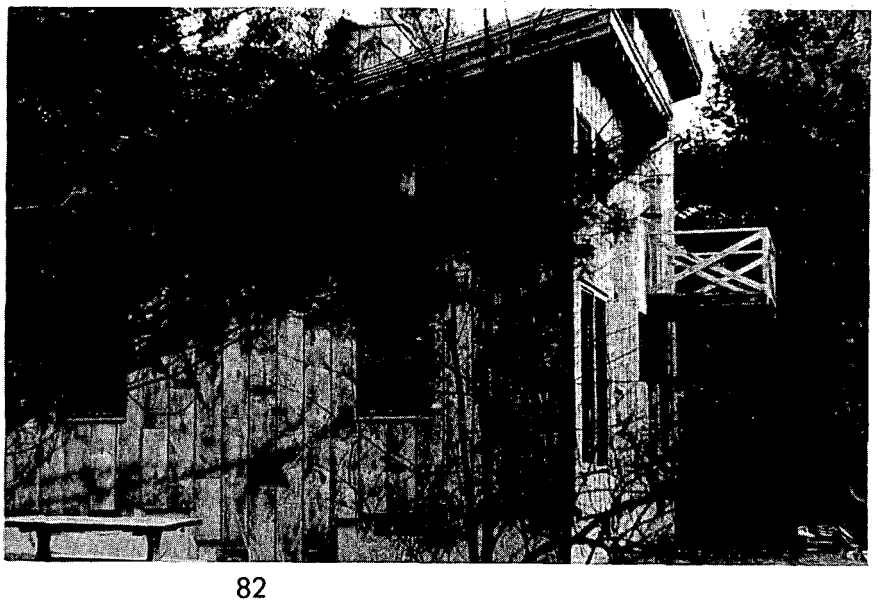
deciduous: refers to trees that drop their foliage at the end of the growing season.

Passive solar design takes note of all these things. It makes intentional use of these and other techniques to cooperate with nature rather than compete with it.

Passive solar design rests on four "knowns":

1. the direction and path of the sun (depending on the season and time of day),
2. the transmittance of glass and other glazings,
3. the natural convection of heated air, and
4. the heat absorption and radiation characteristics of certain materials.

These four bits of knowledge are integrated in any passive solar design.



Adirondack Alternate Energy

Think about these four knowns. What do they tell you? Sun in the southern sky . . . south-facing windows . . . heated air rises . . . paths for heated air . . . heat capacity of different materials . . . materials that heat and cool slowly . . . materials that can store latent heat . . . the collecting space doubling as a living space.

latent heat: the result of an increase in the heat content of a substance without an associated temperature change. (See glossary.)

Let's look at some of the ideas for passive solar design that have developed through the application of this knowledge over the years. We will be talking about houses, but the same principles apply to other structures. All the designs shown on the next few pages have these characteristics in common:

- south-facing glazing admits radiation,
- storage mass absorbs radiation and heats up,
- heated air circulates to cooler areas,

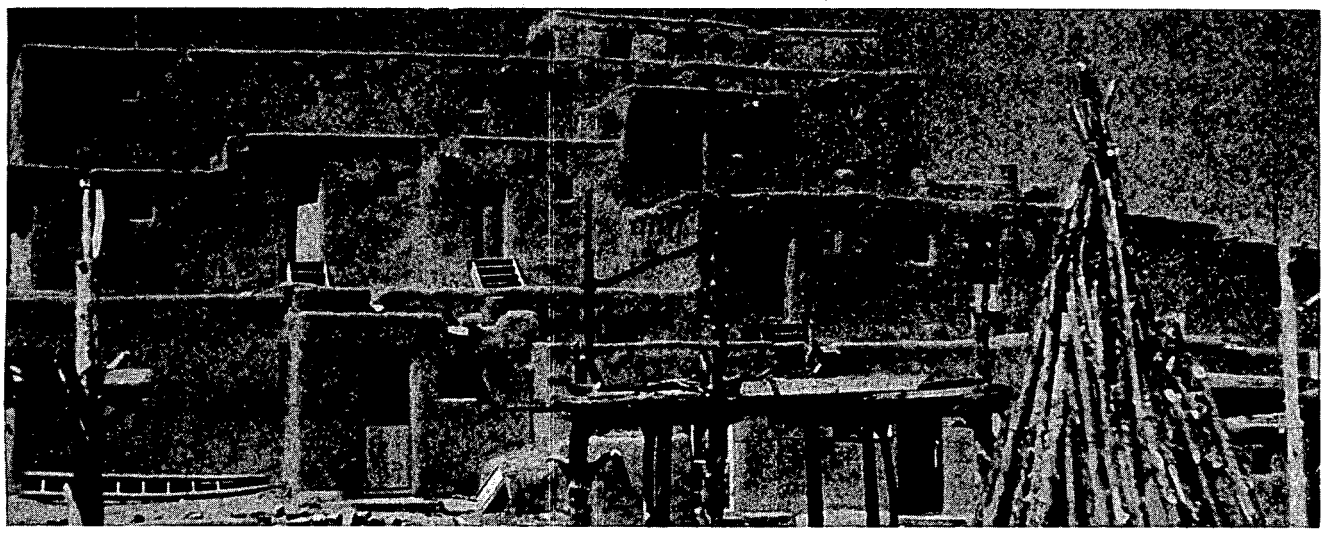
and, in most cases:

- surplus heat circulates to a storage mass for nighttime or cloudy day use.

The Flywheel Effect

Since solar energy is only available during part of the day, it must often be stored for later use. This involves collecting more energy than is needed during sunny periods, so that some of it can be placed in storage. Certain materials, such as rock and water, heat rather slowly and store a relatively large amount of energy in the process. When the temperature of the surrounding air drops, these materials slowly reradiate their stored energy.

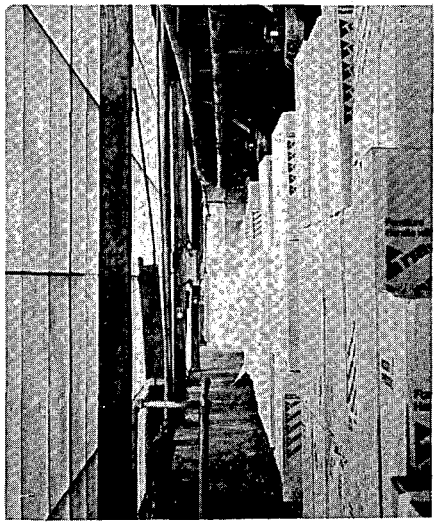
This phenomenon is similar to the functioning of a flywheel on a motor, which stores rotating energy from the motor for later use when energy is not being supplied by fuel. In this analogy the sun is the motor fuel, the passive house is the motor, and the thermal storage materials are the flywheel.



National Solar Heating and Cooling Information Center

Adobe has good thermal storage capacity, heating up slowly during the daylight hours, and releasing its heat slowly at night.

Three Methods of Passive Design



Kalwall Corporation

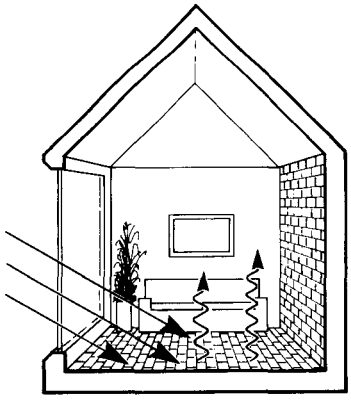
Direct gain provides more than 50% of the heat needed in this warehouse.

Direct Gain

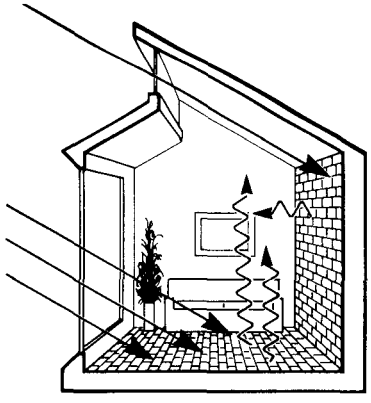
In a direct gain design, areas of glass on the south-facing wall of the house allow the sun's radiation to enter the rooms directly. A masonry floor, back wall, or fireplace structure will absorb some of the radiation, heating up slowly during the day and releasing the heat at night. The heated air of the south-facing rooms rises and is vented along the ceiling to other rooms. Sometimes a fan is used to help circulation.

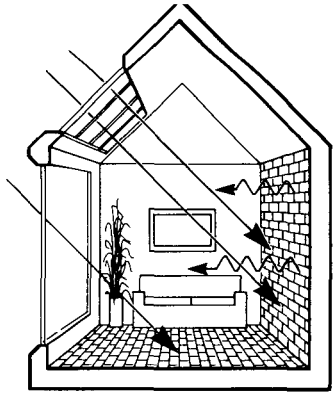
The heated air may also be vented to a storage area, where it flows through containers of water, sand, or other material, warming it slowly. This "storage mass" then slowly releases its collected warmth at night when the air of the house cools.

Examples of direct gain designs are shown here. Notice that in some, skylights or windows placed high on the wall (called clerestories) are used.



Direct gain

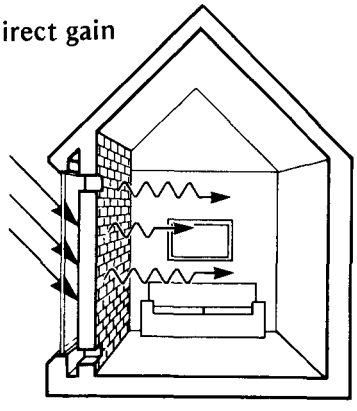


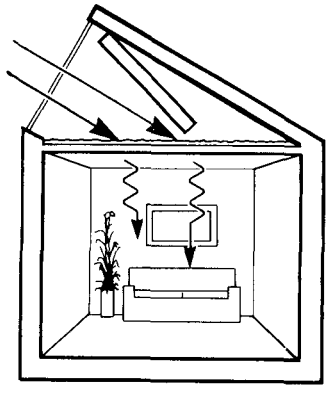


Indirect Gain

With the second kind of passive solar design, radiation is still collected by the structure itself. But the house is designed so that the collecting area comes between the glazing and the living space. The collecting area may be a masonry wall, or a wall or roof made of water containers. Solar radiation passes through glazing on the south-facing wall or roof and is absorbed by the collecting area. This area

Indirect gain





acts as the storage mass, heating up slowly during the daylight hours, and reradiating its heat to the living area during the night. Air circulation around the collection and storage mass also transfers warmth to the living area.

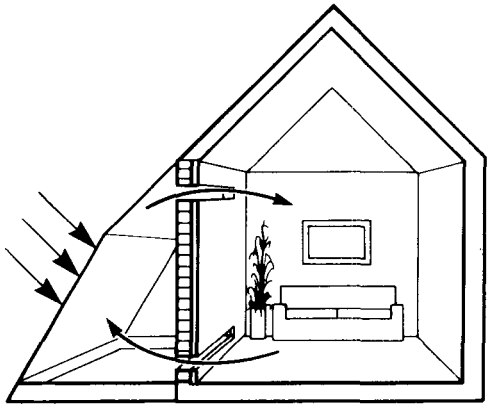
Some of the best known indirect gain designs are Felix Trombe's "Trombe Wall," Harold Hay's "Skytherm System", and Steve Baer's "Drumwall." But there are other interesting and workable modifications on and departures from these models. Some examples of indirect gain are shown here.

National Solar Heating and Cooling Information Center

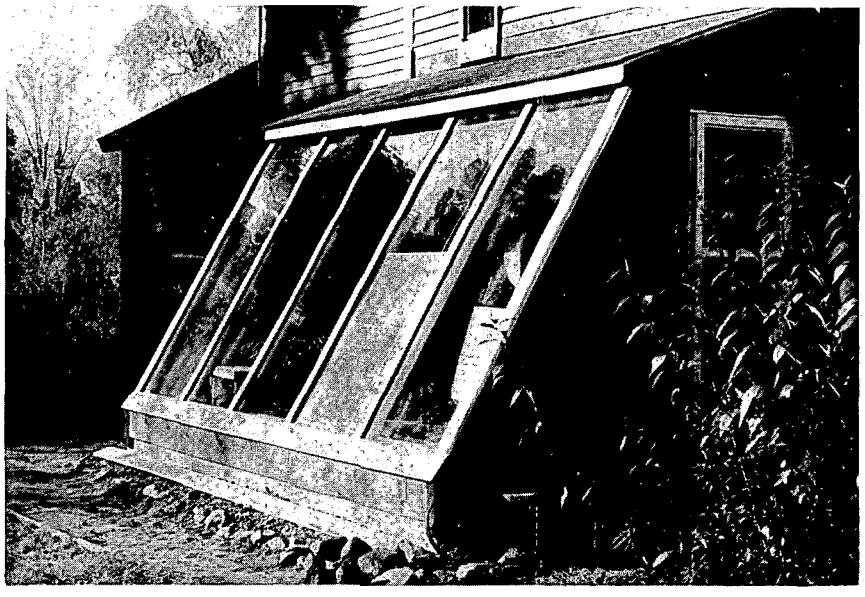
Baer's Drumwall uses black painted drums filled with water for thermal storage. The reflectors are raised at night to insulate the Drumwall.

Isolated Gain

For many people, the most convenient place to collect solar energy is a separate space attached to the house. This can be a greenhouse or sunroom built onto the south side of the house. Masonry floors and walls, containers of water, and beds of earth collect and store energy. As with direct gain systems, it is necessary to circulate the heated air to other parts of the house.



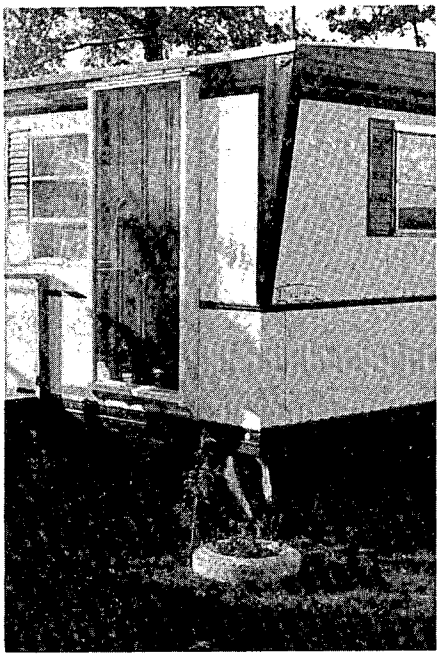
Isolated gain



R. A. Fogarty

An inexpensive solar greenhouse can be added to an existing house.

There are a couple of other systems that fall somewhere between passive solar design and the active solar collectors that we will discuss later. Because they are simple and use natural convection of air, we will mention them here.



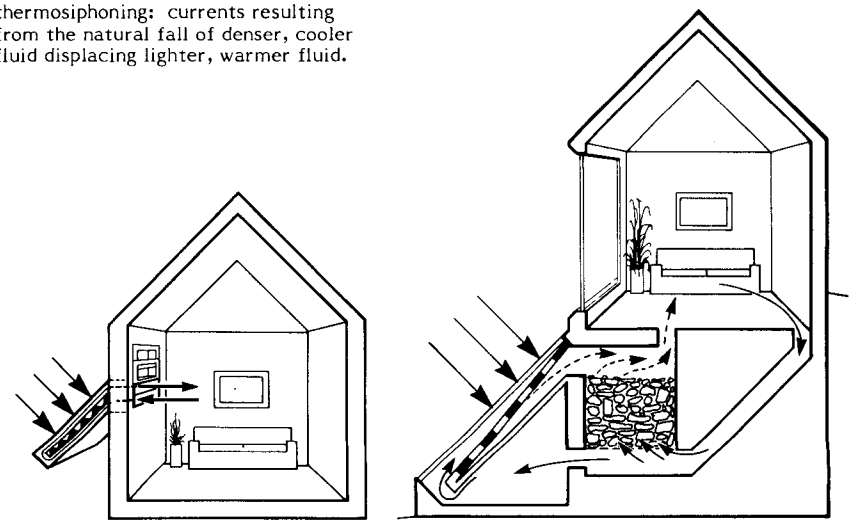
Thermosiphoning collectors help heat this mobile home.

R. A. Fogarty

Thermosiphoning Collectors

The thermosiphoning collector is a flat plate collector mounted outside the house, generally perpendicular to the sun's rays. The collector is connected to the house or to the heat storage mass by in and out vents which channel cool air into the collector and warm air out of it. The displacement of warm air by cool air sets up a convective or "thermosiphoning" loop which helps to warm the house.

thermosiphoning: currents resulting from the natural fall of denser, cooler fluid displacing lighter, warmer fluid.



Window collector **Thermosiphoning collector**

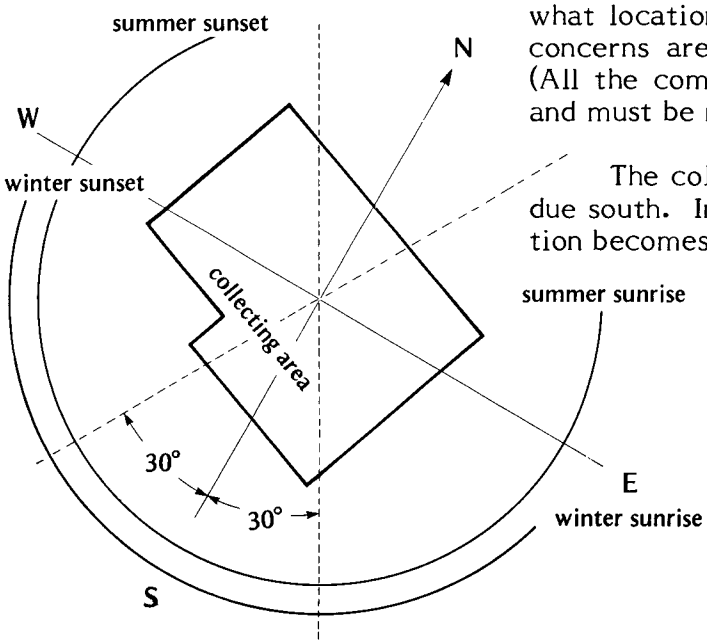
Window Collectors

The window collector, a special type of thermosiphoning collector, is a box that fits into a window opening, and is mounted generally perpendicular to the sun's rays, glazed side up. A dividing panel separates cool air, flowing from the house into the box, from heated air flowing back into the house through the upper, glazed side of the box.

Siting for the Best Solar Gain

Chapters 8 and 9 give a good deal of information about what locations are best for collecting insolation. The main concerns are orientation, lay of the land, and obstructions. (All the comments here refer to the Northern Hemisphere, and must be reversed for the Southern.)

The collecting area should be oriented to within 30° of due south. In the more northern latitudes, due south orientation becomes more critical.



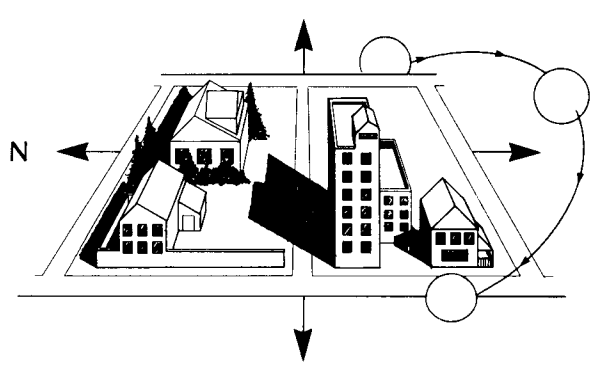
Orientation of a solar house within 30° of south

Land that slopes down toward the south has the advantage of obtaining the greatest solar intensity per unit area, because of the angle of winter sunlight. South-facing slopes also encourage convection of heated air up the slope during the daytime, blanketing the house with warmer air. At night cold air flows down the slope, settling at the bottom. A house partway up the slope will be above the coldest air.

The summit of a hill may have a nice view, but the heat loss from wind makes it a potentially poor solar energy site. East and west-facing slopes both have their own advantages and disadvantages. In colder climates a house on an east-facing slope collects sunlight when it is most needed, in the cold early morning hours. It also has protection from prevailing westerly winds. However, a house on a west-facing slope enjoys more of the warmer, more intense sunlight of afternoon. In warmer climates, on the other hand, a hilltop may be a good spot for natural cooling by prevailing winds, and an east-facing slope will protect the house from hot afternoon sun.

When possible, the building should be sited at the northernmost edge of the property. This gives the property owner the maximum protection from neighboring obstructions to the south.

In the next chapter we will discuss those aspects of siting that aid conservation in a passive solar home, or in any home.



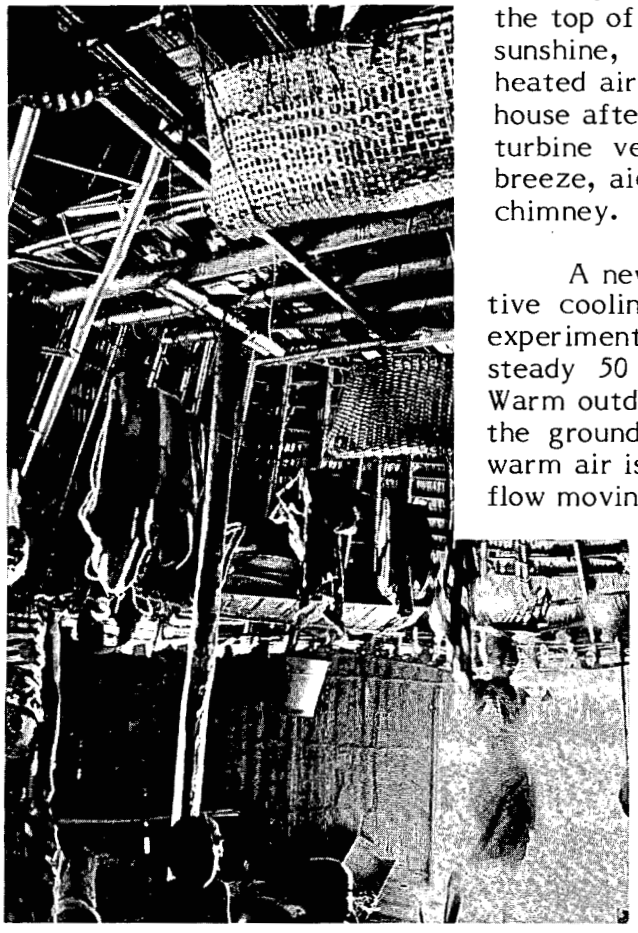
Shadows can be avoided by siting in the northern part of the lot

Passive Solar Cooling

When we think of solar energy we think of heat. But solar energy can also be used to induce cooling. Convection and evaporation, both sun-driven cycles, can be harnessed to cool living space.

The process of evaporation stores heat by absorbing it to change the evaporating liquid to gas. So any system that encourages evaporation will bring about cooling. Gardens, trees, ponds, fountains -- any sources of evaporation -- can cool air moving over or around them. Evaporative cooling works best in a hot dry climate like the American Southwest, where evaporative coolers called swamp coolers are becoming popular.

turbine vent: a revolving set of blades mounted on a chimney to encourage convection.

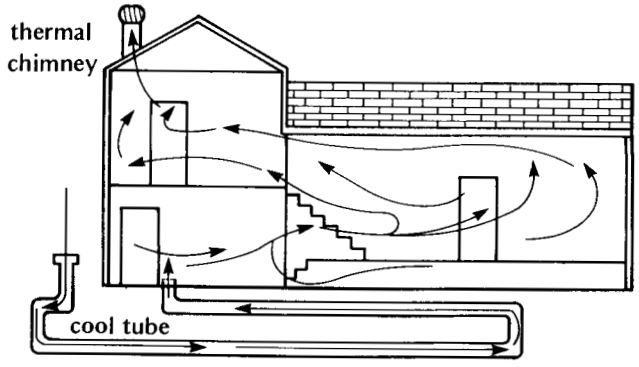


Donald Hegeman

Houses in tropical countries often have high peaked roofs for natural cooling.

Convection also can help to cool, since with convection cooler air moves in to replace rising, heated air. Thermal chimneys take advantage of this natural cycle. Located at the top of the house and purposely designed to heat up in the sunshine, the thermal chimney sets up an air flow. The heated air in the chimney rises, drawing warm air from the house after it, and drawing cooling breezes into the house. A turbine vent at the top of the chimney spins in a slight breeze, aiding natural convection and keeping rain out of the chimney.

A new feature has recently been added to such convective cooling systems. Some homeowners and builders are experimenting with "cool tubes", which take advantage of the steady 50 - 65°F temperatures of the subsurface earth. Warm outdoor air is drawn through ducts for a distance under the ground before it enters the house; in the process the warm air is cooled. A thermal chimney helps to keep the air flow moving.



Passive solar cooling

Sun Tempering: Prevention Is Better Than Cure

The best way to stay cool is to avoid getting hot in the first place. A house that is designed to collect heat in winter can be a hotbox in summer unless one "tempers" the summer sunlight to avoid overheating.

sun tempering: technique for controlling solar gain for summer cooling. (See glossary.)

R. A. Fogarty

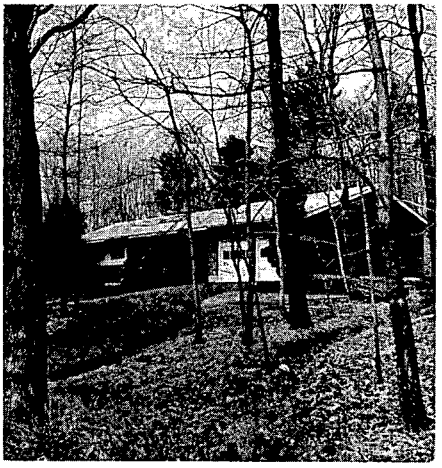
Michael Fogarty

Many older homes are designed for sun tempering.

Features built into or added onto the house can help. One basic sun-tempering feature is an overhanging roof. The overhang doesn't interfere with winter sunlight, when the sun's path is low, but it shields the glazing from hot midday summer sunlight which comes from a much higher angle. Awnings, jalousies, or louvers can serve the same purpose. Blinds or shades with a reflective outer surface can also help as heat shields.

A deciduous tree can be a useful obstruction on the south side of a passive solar home. Its leaves will shade the glazing in the summer, but will fall at the beginning of the heating season to allow sunlight through the bare branches. (Watch out for oak trees, however. Some varieties hold their leaves far into the winter!)

R. A. Fogarty



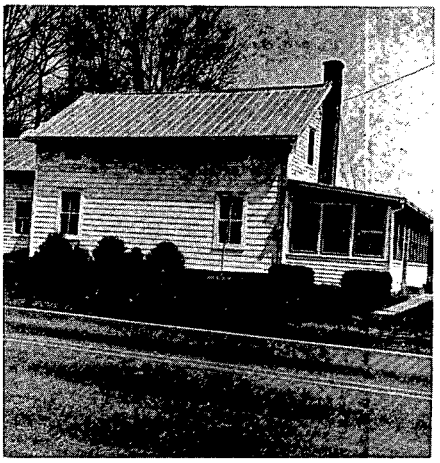
Edward Lalor

Deciduous trees on the south side of a house are a solar asset, but evergreens on the south side can be a mistake.

Many owners of solar greenhouses and sunrooms have found vines like runner beans to be an excellent sun-tempering device. The vines, planted in spring, climb up to shade the glazing with their leaves all summer. At harvest, the vines are removed and the glazing is ready to admit sunshine again.

Retrofitting for Passive Solar Gain

Parts of this chapter may seem to imply that passive solar design is only for new houses, but this is far from true. Much can be done with existing houses to take advantage of the sun's energy. With any house, conservation comes first. But after that you can "retrofit" an older house, that is, make changes or additions that improve its ability to use solar energy. Mobile homes too can be retrofitted successfully.



Edward Lalor

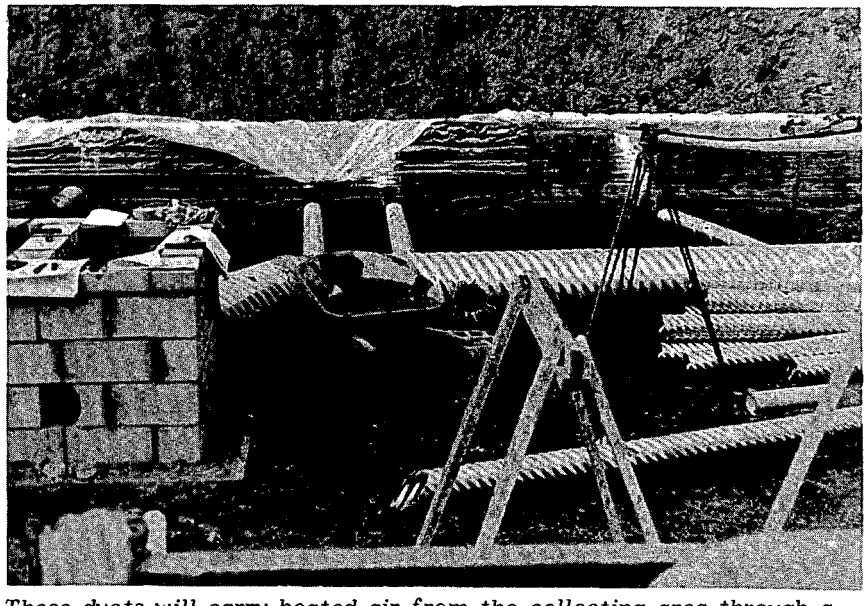
retrofit: to modify an existing building to improve its energy efficiency.

Troubleshooting with Passive Solar Design

Your best aids to successful solar design are knowledge and experience. You can get these by reading, and by talking with people who have tried different systems. Many solar builders disagree about the amounts of glass, insulation, and storage mass that are appropriate for a given house. They will argue about the relative merits of sand or water as storage materials, criticize each others designs, and predict doom if you use their competitor's insulation. Listen, evaluate, read, and make your own informed judgments. (The bibliography at the end of this book will help you.) Here are a few problems to watch for:

Temperature Fluctuations

The sun is a powerhouse, and passive design is very effective. So the collecting and living area of a passive solar building can actually overheat. If the design circulates air effectively (using small fans if necessary), and if the storage mass is large enough, the living area should remain comfortable.



Adirondack Alternate Energy

These ducts will carry heated air from the collecting area through a basement storage mass.

The best insurance against underheating is good insulation, but for severe climates or those that experience long cloudy periods, a back-up heating system is necessary. This system, be it electrical, wood, or whatever, can often be integrated with the solar air circulation system.

Materials Degradation

Ordinary paints, caulks, plastics and fabrics will often blister, crack, and fade as a result of continued exposure to solar radiation and heat. Check to see how materials have been tested, and make sure that they are designed to withstand the sun, especially ultraviolet radiation.

Microorganisms

Two systems have been pointed to as likely to experience a buildup of microorganisms: rock storage bins and cool tubes. In both of these, cooling may occur to the point where condensation forms in the system, providing a good breeding ground for spores and bacteria. If either system is considered, steps should be taken to control condensation and prevent possible problems.

Fire

Any house is designed with an eye to air circulation, but it's well to remember that where air goes, fire goes. So in considering passive solar designs, where air circulation is important, some thought should be given to fire prevention and control. The design should be planned and materials chosen with this in mind.

Managing a Passive Solar Building

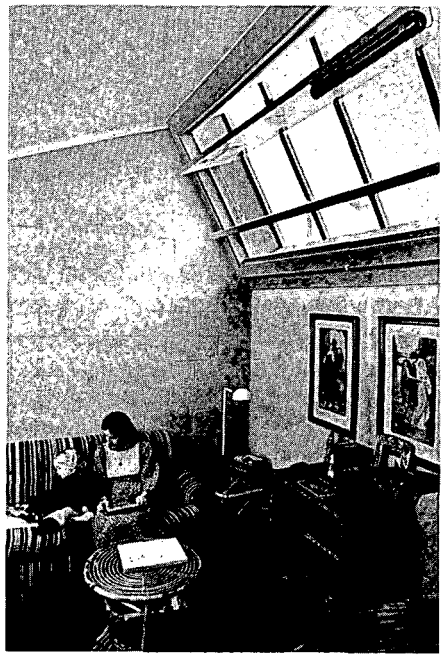
A well-planned passive solar design may "run itself", but initially it will probably need to be monitored. All the energy collected through south-facing windows in the daytime can seep back out at night if the glazing is left uncovered. Someone must make sure that this doesn't happen.

R. A. Fogarty

Insulating shades or drapes are a nighttime necessity for passive solar houses.

sun sensors: sun-sensitive devices that can be used to control systems.

Sun sensors have been devised to automatically open and close insulated drapes or blinds at the appropriate times. However, these systems are still somewhat experimental (not to mention expensive). Most solar home owners seem to find the management of their system pleasant, not troublesome. For people who are willing to open and close drapes or shutters at set times, mechanical devices may be unnecessary.



Solar Applications and Research Ltd.

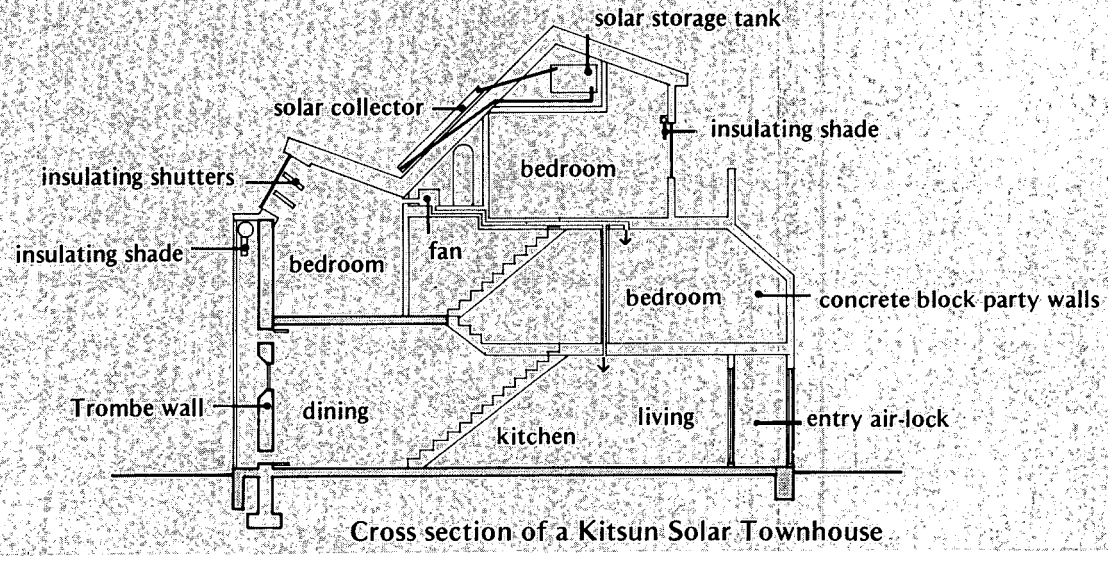
Skylid insulating louvers by Zome works are opened and closed automatically with power from heat-sensitive canisters attached to the louvers.

A Present Solution

More than one fifth of our energy consumption goes to heat and cool living spaces. This need for energy is widely distributed; it exists wherever people live and work. Yet it is not a need for high quality energy, like steam or electricity. All that is required is sufficient energy for comfortable human activity. Passive solar design is an appropriate solution for this need.

Solar Townhouses

The Kitsun Solar Townhouses in Vancouver, Canada, are an example of passive solar design. The cross section of a townhouse shows direct gain, indirect gain (Trombe wall), and thermosiphoning flat plate collectors for water heating.



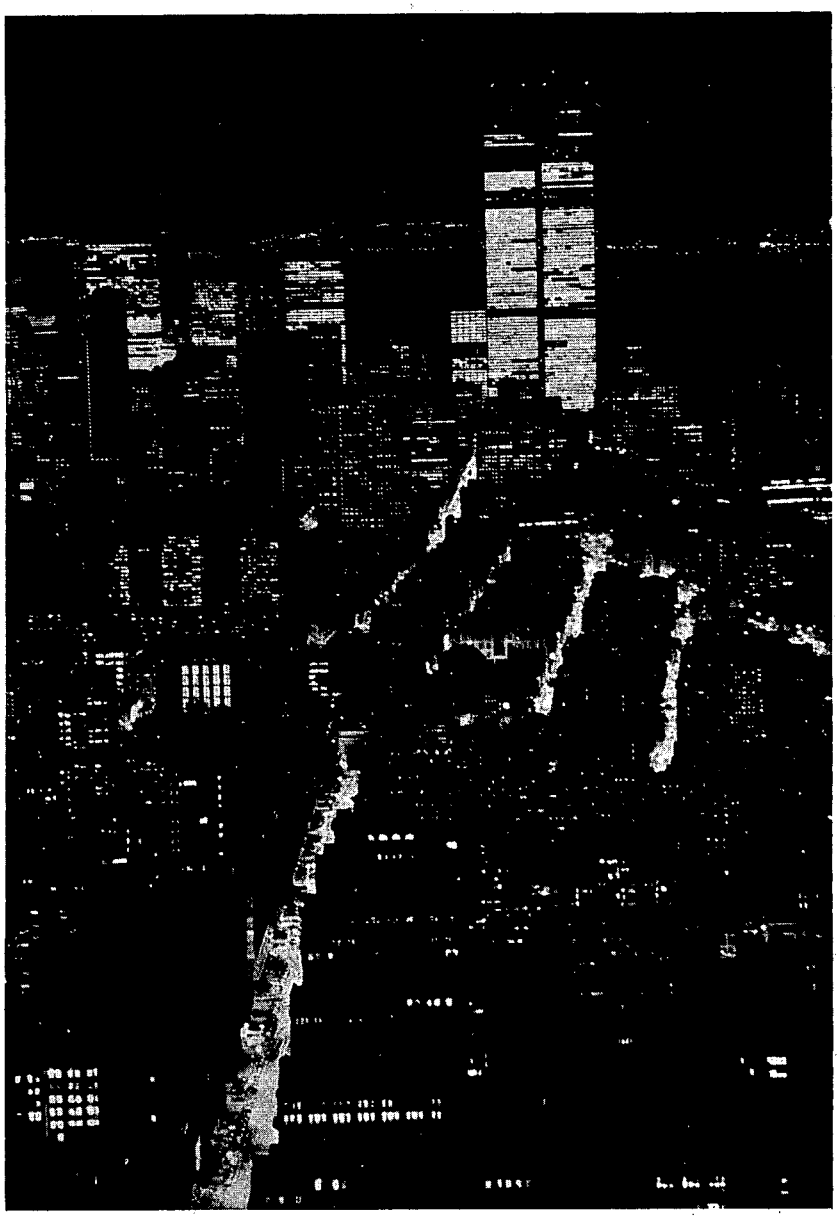
Cross section of a Kitsun Solar Townhouse

Solar Applications and Research Ltd.

The energy of the sun can be used at the point where it is received, so there is no need for transmission. Passively collected solar heat is at the proper temperature for heating living spaces. Most important, passive solar design is not just "a promising technology for the future". It is here now; it has arrived. Common sense urges that we begin to put it to use.

Chapter 12

Saving What You Gain

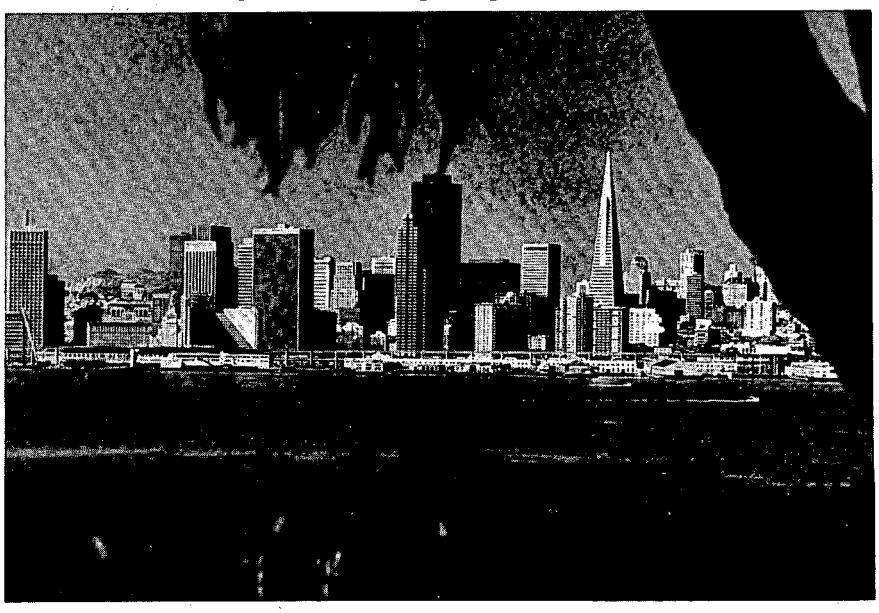


N.Y.S. Department of Commerce

The fastest and cheapest way to obtain new energy today is to save the energy we've got. Even among the debates and disagreements of energy experts, this point seems to emerge clearly: energy conservation is the most immediate solution to our problems. It cannot be the final solution; for that, new sources of energy must be used. But as traditional fuels dwindle, saving measures that once seemed too troublesome are now widely accepted.

A multitude of creative ideas for saving, sharing, and recycling energy has resulted. Designs for more efficient

cars, lighting fixtures, or industrial processes; plans for changing the energy habits of workers, drivers, or families; blueprints for broadened public transportation, a restructured workday, or new dietary patterns; systems for recycling industrial process heat; philosophies for returning to the clothesline, the woodstove, the one-pot organic meal -- a veritable explosion of energy ideas and information has occurred. Long or short-term, practical or visionary, technological or sociological, these ideas show the ferment of a society reshaping itself through argument and experiment.



San Francisco Visitors Bureau

This chapter cannot begin to discuss all these theories and plans. The bibliographies for this chapter and for Chapters 10 and 11 will lead you to sources of information on all aspects of energy conservation. Here, we will focus on ways of conserving heat in living spaces, because this form of energy conservation is most directly connected with solar energy.

There is no point in collecting solar radiation through the windows if it immediately flows out through the walls. With any heating system energy conservation is important; with solar energy it is especially essential. Without it, a solar system can be vulnerable to season, wind, and weather. With it, a solar system can be partially or even completely independent.

In thinking about conserving heat, it helps to think of heat as a fluid seeking its level. Heat will flow from areas of high temperature to areas of lower temperature, until equilibrium is achieved. All the heat you produce in your home by collecting sunlight or burning gas or oil or coal or wood is naturally going to flow into and through cold windows, ceilings, floors, and walls unless you stop it.

If you can reduce the temperature difference between the indoor side of those surfaces and the interior air, you can slow down the rate of heat flow by conduction. Heated air is also going to move out wherever there are cracks or holes

that give it the opportunity. Forced cold air (wind) will seep in through those cracks and mix with or displace warmer air. To stop this "infiltration" and "exfiltration" you must plug the cracks and holes.

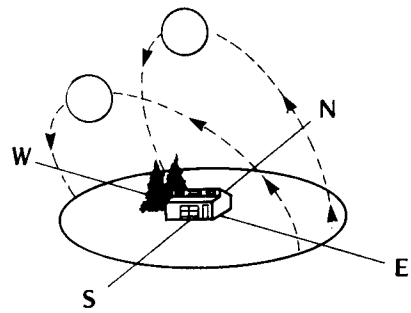
infiltration: the uncontrolled movement of outdoor air into a building. (See glossary.)

exfiltration: the uncontrolled movement of indoor air out of a building. (See glossary.)

It would help if we could see heat with our eyes, as we can on infrared film. Since we can't, we have to use knowledge and common sense to figure out where we're losing heat and how to keep it.

The Outside

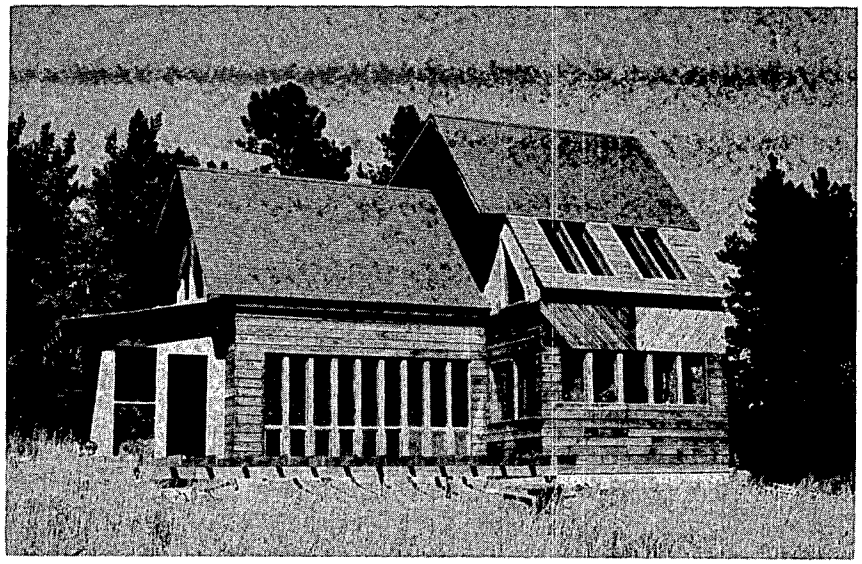
Begin by looking at a structure as a whole, from the outside. In the Northern Hemisphere most solar energy falls on the south face of the house during the cold months. It is on the south side that you want to admit sunshine. What about the other sides then? Although windows are needed for solar gain, they can also be responsible for a tremendous amount of heat loss since glass is a good conductor. A single-glazed window can be responsible for twenty times as much heat loss as an area of wall the same size.



Sun's seasonal paths in the Northern Hemisphere

It may not be practical to eliminate all windows on the north side, but they should be carefully evaluated for function, and triple-glazed or insulated if possible. (More about this in the section on window treatments.)

The east and west sides also present a problem. Some solar gain takes place on these sides, but so does heat loss. East-facing windows may be important for collecting radiation early in the day, when the structure is cold, especially if the rooms are arranged so that those most used in the morning are on the east side. West-facing windows can add heat to the house on hot summer afternoons, and prevailing western winds steal a lot of heat from west-facing windows in winter.



Hannigan & Associates, Inc.

The best plan for structures in the northern latitudes is to concentrate window areas on the south side, and avoid window areas to the north. In warmer latitudes, with different seasonal solar paths, windows should be concentrat-

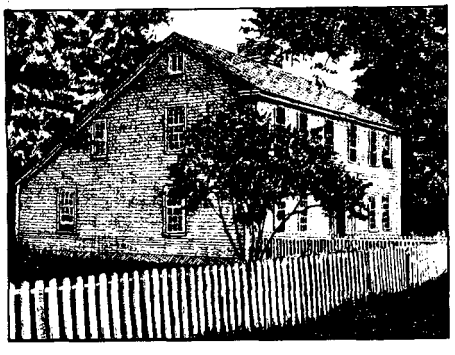
ed on the north and south, with shading or roof overhang over the southern windows. This will allow winter heat gain but cut down on summer heat gain, and the northern windows will provide summer cooling.

Still looking at the outside of the house, what else can be done to save energy? Many modern builders, like the pioneers of the sod-house days, are building into hillsides so that the north side of the house is virtually buried. Some houses are built completely underground where the moderating effect of the earth's temperature greatly reduces the need for heating. An underground builder has to be aware of potential problems with moisture, however.

Another approach is to build above ground, but then pile up a bank or berm of earth on the north and west sides of the structure for natural insulation. An unheated garage or shed attached to the north or west side has insulating value, too, and so does a woodpile.

R. A. Fogarty

Attached garages on the north side will help to insulate these townhouses.



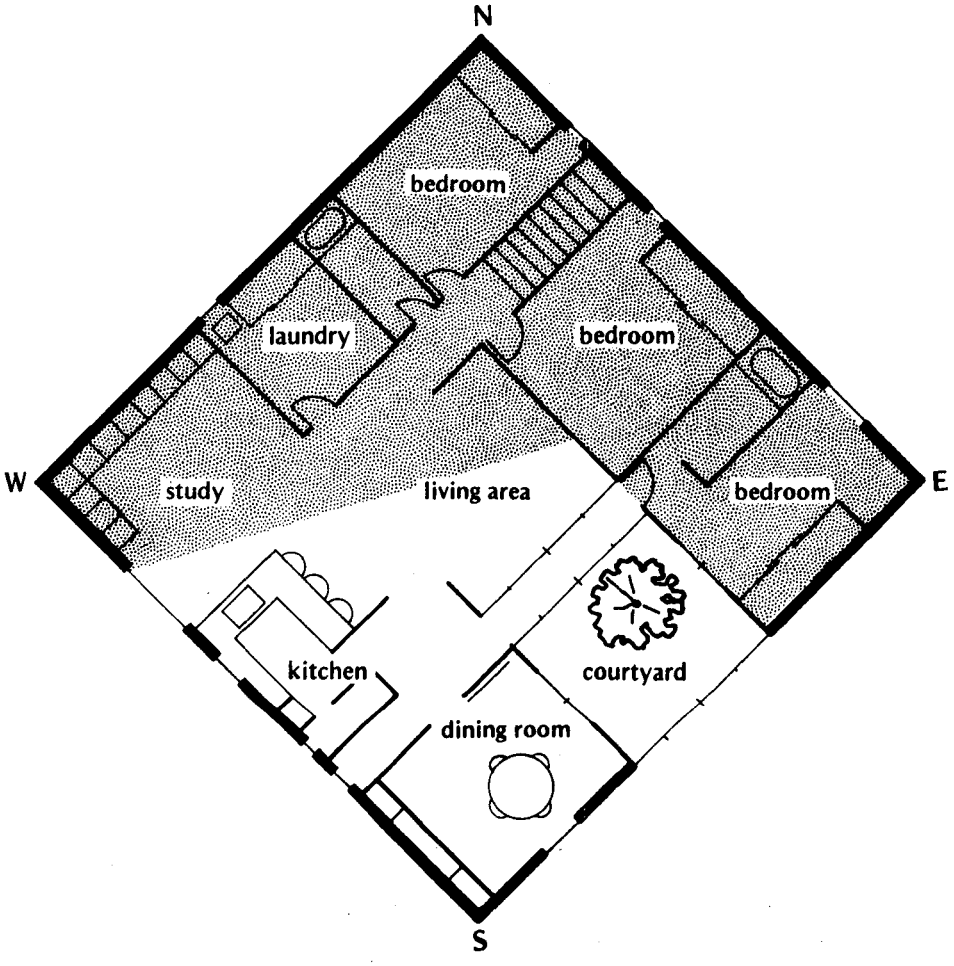
Many early houses were well designed from an energy standpoint.

On some houses like the New England saltbox the roof on the north and west side descends almost to the ground. The wind is routed up and over the house, instead of striking the walls full force. Another way to shunt wind over the house is with an evergreen windbreak. Estimate the height of the house, and locate the windbreak two to five times that distance windward of the house. Hemlock, fir, and spruce are good choices for a windbreak.

The Inside

As we go indoors in our search for ways to save heat, we let in a blast of cold air. One of the first barriers to infiltration of cold air is an airlock entry, such as a small vestibule or closed porch. A storm door alone is not enough. It reduces conduction, but not infiltration, because it is usually open at the same time as the main door.

Once inside, let's consider how the working or living spaces are arranged. Daytime heat is not usually important for storage areas, closets and bedrooms. In designing a building it makes sense to range these areas along the north side of the structure, where they can act as a buffer zone for the more heavily used living and working areas.



Energy-efficient room arrangement

Insulation

When it comes to heat loss by conduction, we have to consider insulation. There are many insulation products, made from a variety of materials, but the most important component in all of them is the same -- air. Air is a poor conductor, so the millions of tiny air spaces in insulation materials slow down heat conduction.

insulation: material with high resistance to heat flow. (See glossary.)

R-value: a measure of a material's resistance to heat flow. (See glossary.)

Below is a table listing a number of insulation materials. Next to each is a number which represents the material's resistance to heat flow. This factor is called the material's "R-value". The higher the R-value, the greater the resistance.

INSULATION MATERIALS, R-VALUES, AND USES

Material	"R" per inch thickness*	Where Used
Flexible		
Cellulose fiber with vapor barrier	3.20-4.00**	unfinished attic floors, open sidewalls, heating ducts, crawl spaces, underside of floors, rafters
Glass fiber or mineral wool	3.00-3.40**	
Loose Fill		
Glass fiber and mineral wool	2.80-3.40	finished and unfinished attic floors, finished frame walls
Cellulose	3.50-3.70	
Vermiculite, expanded	2.13	
Rigid Board		
Polystyrene, extruded	5.26	basement walls, new construction, floor slab perimeter
Expanded urethane, preformed	5.80-6.25	
Glass fiberboard	4.00	
Polystyrene, molded beads	3.57	
Foamed-in-Place		
Expanded urethane, sprayed	6.25	finished frame walls, finished and unfinished attics
Urea formaldehyde	5.00***	finished frame walls

* Determined from ASHRAE Handbook, 1972
** Varies according to density and fiber diameter
*** From manufacturers' specifications

Recommended R-values for regions of the U.S.A.

Every type of insulation seems to pose some kind of problem. Some are flammable, some retain water, and some tend to settle and lose part of their effectiveness. Some insulations are feared to emit hazardous gases, others to be carcinogenic if particles are inhaled. Each type has to be evaluated as to use, location, cost, R-value, and potential hazards.

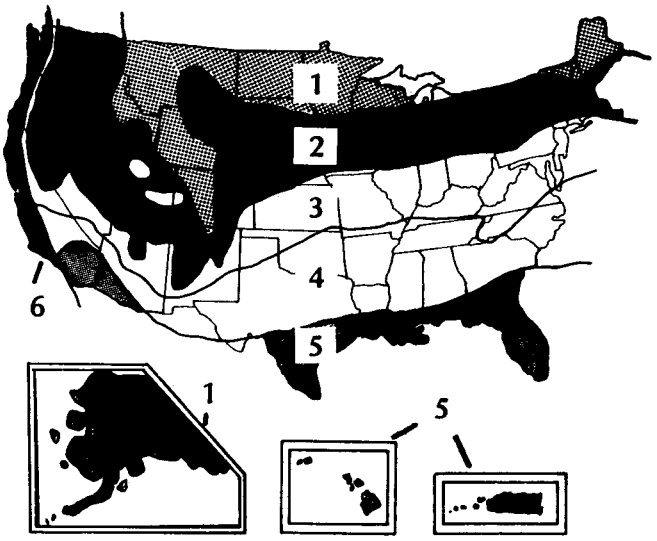
Underwriters Laboratories, Inc., tests and rates insulation materials for flammability and smoke development. It also tests some insulation, primarily cellulose, for R-value. The National Association of HomeBuilders (NAHB) Research Foundation, Inc., independently tests and rates insulation for R-value, and this rating should appear on any package of insulation you buy. In addition, retailers, builders, and insulation contractors are required by the Federal Trade Commission to supply you with a fact sheet on any insulation you are considering using.

Recommendations for amounts of insulation vary from R-20 to R-40 for ceilings, and R-10 to R-20 for walls, depending on region and weather. The best time to insulate, obviously, is when the structure is being built. With an existing structure, insulating is more difficult, so it makes sense to do the best possible insulating job during construction. Some owners add insulation to existing buildings by drilling small holes in the walls between the studs and blowing in loose or foam insulation. The problem here can be shrinkage or settling. Another technique is to cover the outside of the house with foam board and add new siding over it.

RECOMMENDED INSULATION R-VALUES

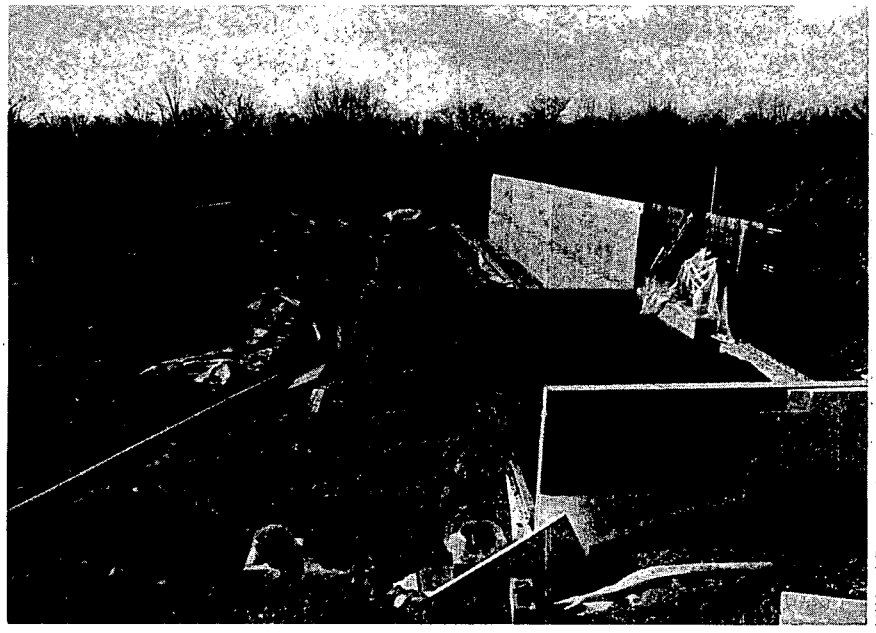
R-Value:	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
Ceilings	38	33	30	26	26	19
Walls	19	19	19	19	13	11
Floors	22	22	19	19	11	11

These recommendations will vary for individual homes, depending on (1) your heat source (electrical resistance, gas, oil); (2) local weather variations; and (3) the amount of insulation presently in your home. In existing homes, wall cavities may be only 3½", room enough for no more than R-13 insulation.



Fortunately, most attic spaces are accessible for insulation, and builders agree that this is the most important place to insulate. Because of convection, the warmest air in the structure is that near the roof, so severe heat loss can result. If the attic has no floor and is unheated, the space between the joists can be insulated with blanket, board, or loose insulation. If the floor is finished, loose insulation can be blown in. If it is a heated attic the space between the roof rafters can be filled with blanket or board insulation.

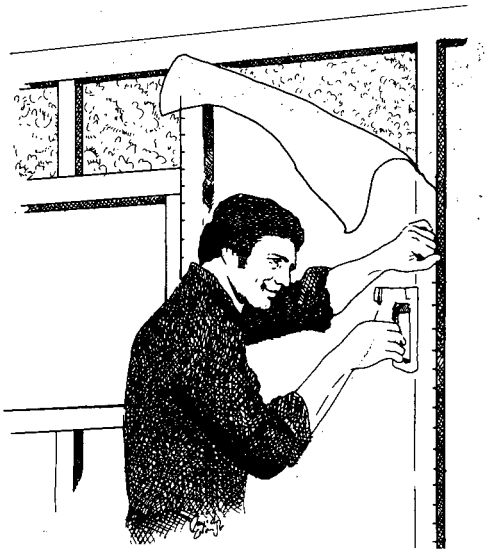
It is also worthwhile to insulate the ceiling of an unheated basement or the walls of a heated one. If the house is built on a slab, the slab can be insulated underneath during construction. Many builders now insert foam board insulation all around the outside of the foundation to below the frostline.



Milford Reservation, Inc.

Foamboard insulation is being used around the outside of the foundation of this building.

vapor barrier: a waterproof liner used to prevent passage of moisture. (See glossary.)



Tacking up a vapor barrier

Vapor Barriers

To work well, insulation should be dry. But the interior of a house has many sources of moisture: cooking, bathing, and the human body itself. The heated air in the house contains water in the form of vapor. If the ceiling or walls are cold the vapor will condense on them or in them. Eventually the insulation in the walls and ceilings can become damp and lose much of its insulating ability.

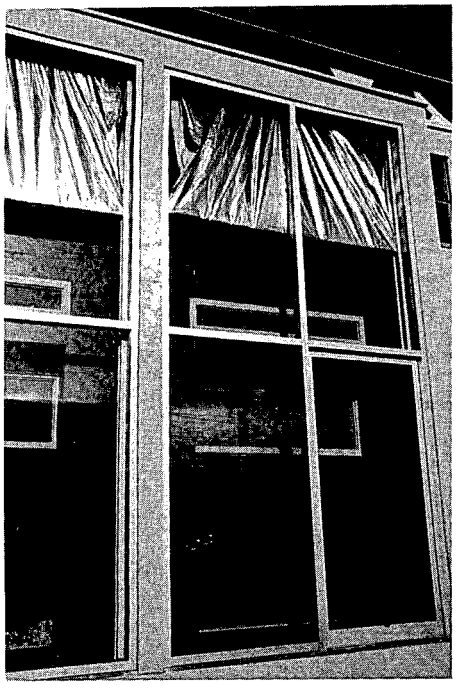
To prevent this, insulation is often installed with a "vapor barrier," a sheet of plastic or foil, between the insulation and the inside of the house. The vapor barrier may be attached to the insulation when you buy it, or may be installed separately. Remember, the vapor barrier must always be on the warm side of the insulation. Then, when vapor passes through the walls or ceiling, it encounters the vapor barrier and can't get into the insulation to saturate it.

Window Treatments

In terms of saving heat, the ordinary window (except where it is used to collect solar energy) is almost as bad as a hole cut in the wall. Heat pours out through the glass. But people like windows: they like the natural light, the view, and the sense of space that windows give. The office with windows, the restaurant table by the window, the picture window in the living room -- all are prized commodities. How can this energy liability be turned into an asset?

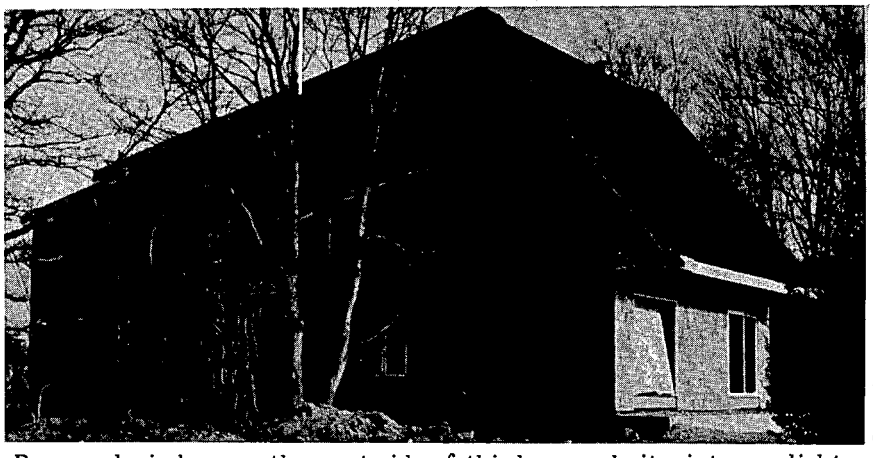
We have already discussed orientation of windows and placement of rooms. If most of the daytime living space (with windows) can be concentrated on the south side of the structure, and most of the storage and sleeping space (without windows) is on the north, then part of the problem is solved.

Another step is to add a second or third layer of glazing, perhaps storm windows or plastic sheeting with a small airspace in between. (A vacuum is even better than an airspace for reducing heat losses.) Additional glazing reduces the amount of solar energy that can enter, however, so solar builders often recommend only single or double glazing for the south side, and triple glazing elsewhere.



Solar Applications and Research Ltd.

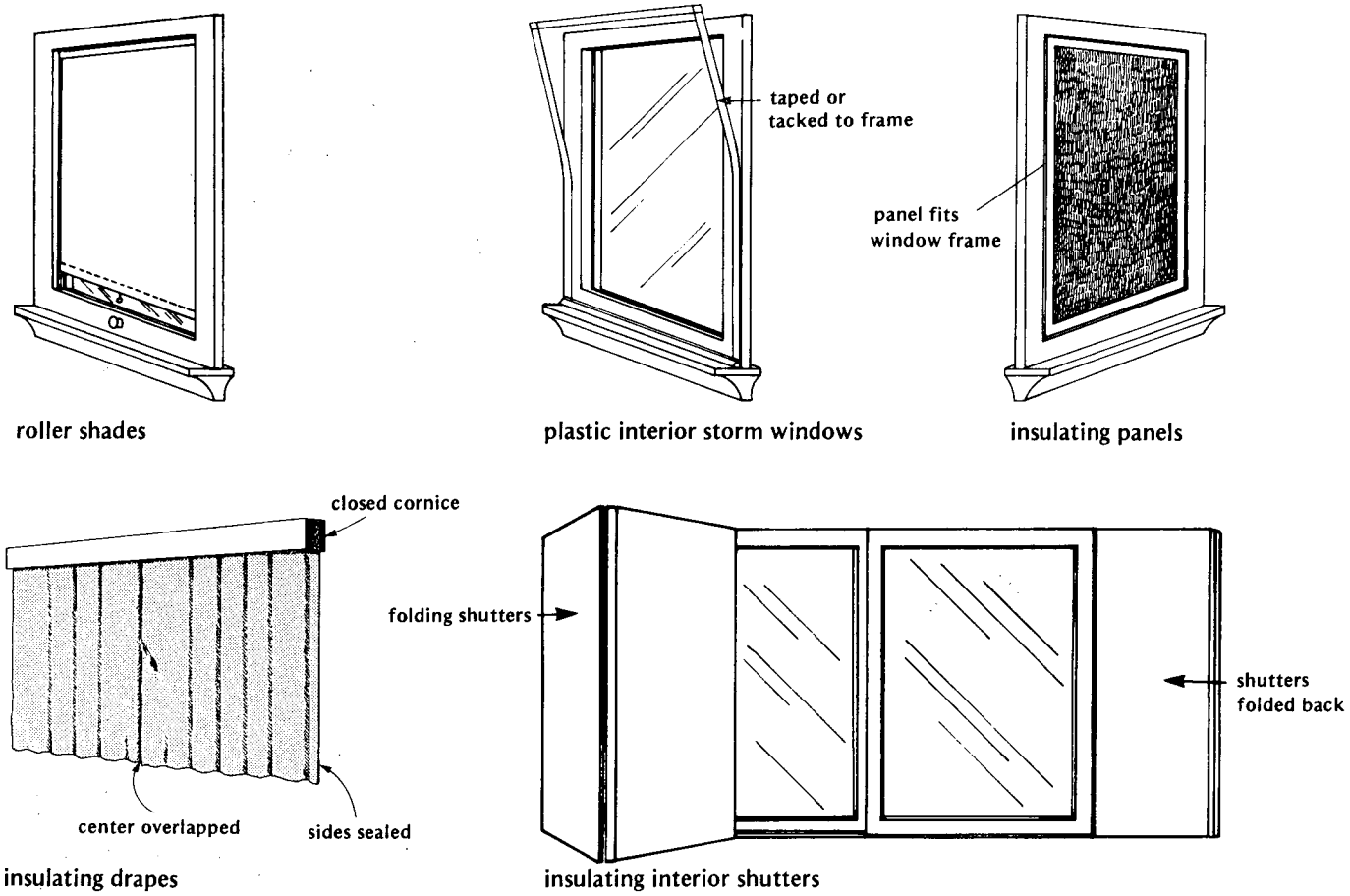
Insulating shades keep the heat stored in this Trombe wall from escaping at night.



Solar Thermal Systems

Recessed windows on the west side of this house admit winter sunlight but are shaded from summer sunlight.

All windows, even south-facing ones, lose heat by conduction and radiation at night. Dozens of devices for night insulation of windows have appeared in the last few years, some commercial and some homemade. A few are shown here to suggest the variety of ideas available.



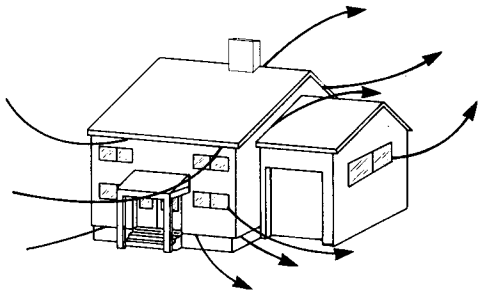
Window treatments for nighttime use

It is important for any window insulation to fit tightly around the edges of the window; otherwise, air convection around the insulation will carry warm air past the cold window surface and actually accelerate heat loss.

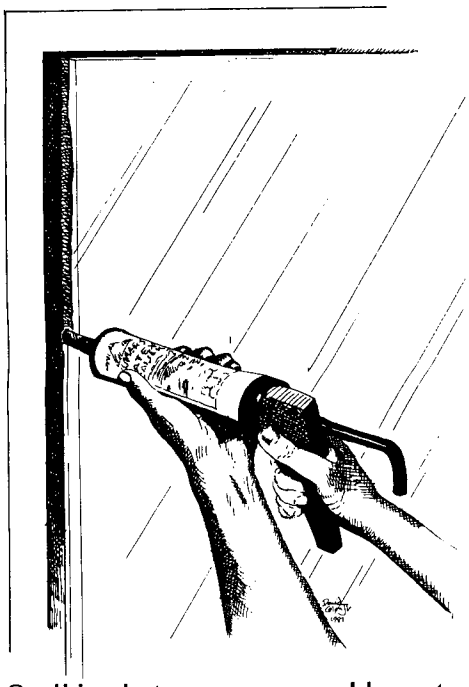
Plugging the Leaks

Imagine heat as a liquid, and the heated structure as a container full of this liquid under pressure. Can you think of all the places where that liquid would squirt out? No house can or should be completely airtight, but thanks to years of cheap energy, most of our houses are built like sieves. Any places where the roof or walls of the structure have been pierced (chimney, stove pipes, dormers, windows, air conditioners, doors, exhaust vents, outdoor faucets) are vulnerable. So are places where two materials meet (the soleplate where wall meets floor, electrical outlets, the edges of window glass).

One way of detecting air flow at these spots is to dangle a piece of tissue paper in front of them. If there is air flow, you'll see the tissue move. Another draft detector is a lit cigarette lighter, or a feather suspended on a thread. Even without a draft detector, you can assume that most of the places shown in the picture below are responsible for heat loss.



Heat leakage by infiltration and exfiltration

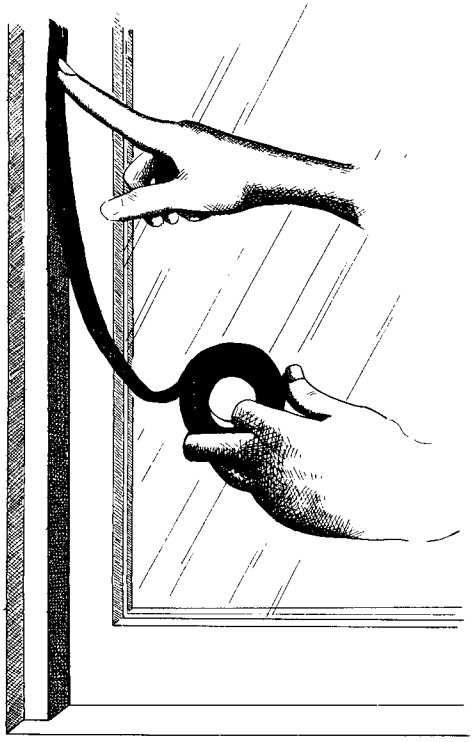


Caulking between nonmovable parts

caulking: a soft, semi-solid material that can reduce air flow through cracks in a building. (See glossary.)

Caulking and weatherstripping are the two products commonly used to beat heat leaks. Caulking comes in squeeze tubes, cans, or cartridges which fit a caulking "gun". It is a soft material which hardens after it is applied. It can be used to fill and seal any small spaces or seams where there are no moving parts. Use it around window frames, where pieces of siding meet, where door and window frames meet the siding, etc. Caulking can be a time-consuming task, so it's worthwhile to buy a good caulking compound that resists cracking and shrinkage.

weatherstripping: material applied around door and window frames to reduce air flow. (See glossary.)



Weatherstripping where moving parts meet

Weatherstripping is used where moving parts meet. There are different types (felt, foam, sponge rubber, or metal) for different situations (doors, windows, garage doors). Sliding doors and windows are especially important candidates for weatherstripping.

With both caulking and weatherstripping, you should make a complete survey of the types available. Consider use, cost, looks, and durability before you buy.

Air Quality in Tight Houses

What happens to the air in a very well-insulated structure? Is it possible to make a house "too tight" for human health? Yes, say some researchers. Various forms of pollution may exist in a house: oxides from gas stoves or furnaces, aldehydes from building products, and radon gas from some soil, groundwater, and masonry. If there is very little indoor/outdoor air exchange, these pollutants may reach dangerous levels.

The ongoing study of this problem has generated a number of suggested solutions:

- maintain 0.5 air exchanges per hour (less air exchange than in most conventional houses but more than in some energy-efficient houses;
- don't use a gas appliance (stove, dryer, furnace, etc.) in an energy-efficient house;
- avoid thermal storage materials that emit radon;
- install an air-to-air heat exchanger (a box with a baffle construction, installed in the wall, which allows escaping air to give up its heat to entering air).

This chapter has been aimed primarily at the problem of keeping heat in. But since a certain percentage of our energy goes to airconditioning, we should also be concerned about keeping heat out at times.

If we take the same principles and turn them around, we can conserve energy as effectively in summer as in winter. Attic insulation pays off in summer. Where windows are concerned, shades and drapes can help, but it's best to prevent radiation from passing through the glass in the first place. Once it's in, it's hard to get rid of. Roof overhangs, awnings, outside jalousies and blinds are most effective. Many people effectively block the sun's rays by planting vines in the spring that will shade the windows in the hot months but drop their leaves in the fall.

Energy Conservation and Lifestyle

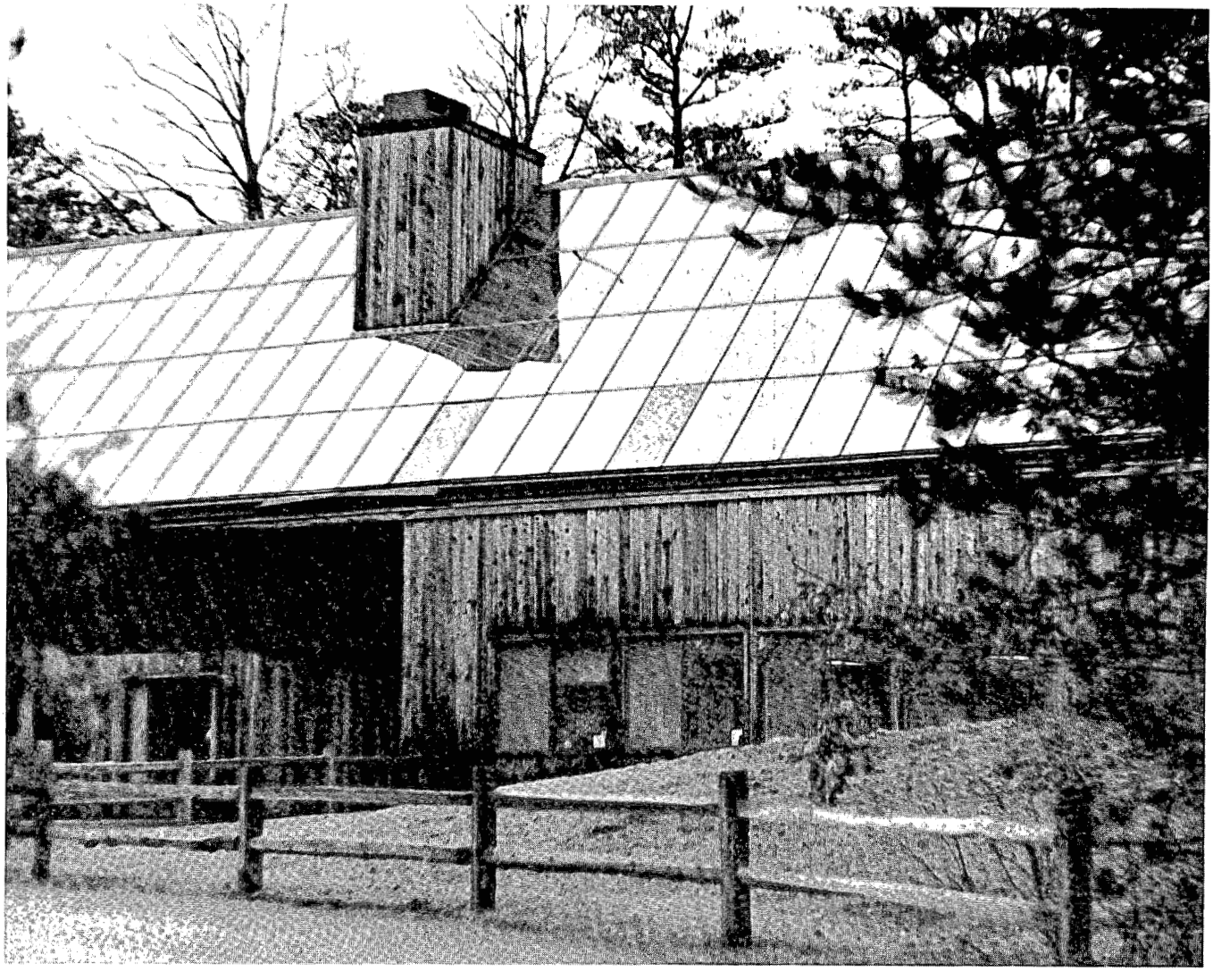
People tend to think that the present energy problems will inevitably lead to a lowering of our standard of living. Yet there are countries with a higher standard of living than that of the United States, that use less energy per person than America does. The key is conservation. The energy that is leaking from our homes and workplaces is not improving our lives; on the contrary, it is causing us discomfort, anxiety, and expense.

Chapter 13

Collecting Sunshine Actively

The difference in definition between active and passive solar is beginning to blur a bit. This is natural in such a practical field. What a solar design is called matters less than how well it works.

"Active solar" is traditionally defined as any technology that collects, circulates, and stores solar energy with the help of added energy, i.e., from pumps or fans. The problem is that many passive solar designs now use fans to improve efficiency but are still called passive. What else, then, sets active solar apart from passive?

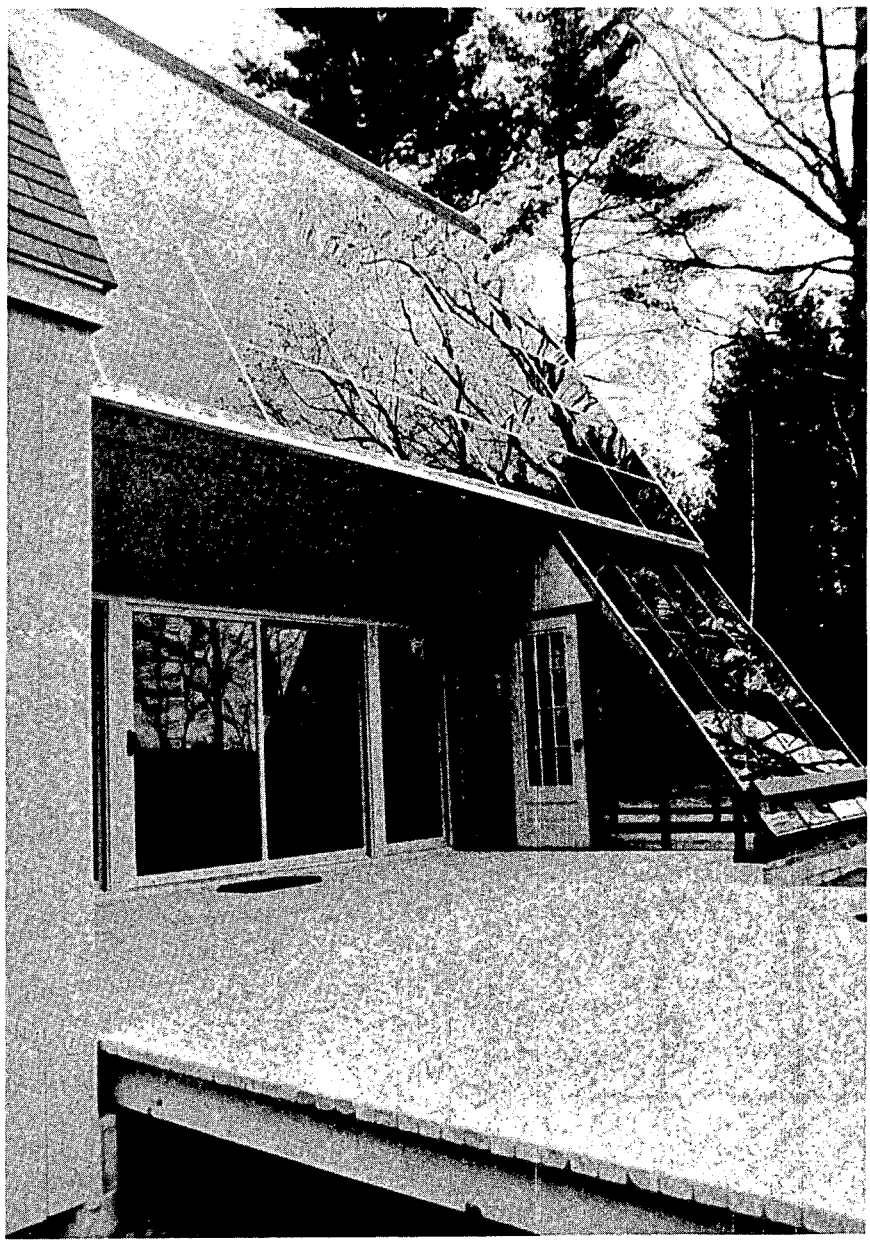


Passive solar refers to living space that doubles as a solar collector. Active solar doesn't double as anything. Its sole purpose is to collect solar energy as efficiently as possible. So an active solar collector may be mounted on a roof or wall, or placed in a yard or field. In fact, acres of solar collectors may be set up in an open area.

Hybrid Solar

The term "hybrid" refers to solar houses which use both active and passive components. Typical examples might include a house with passive space heating but solar collectors for heating domestic hot water, or a house which combines passive window areas with an active collection and distribution system (fans or pumps) to move heat to where it is needed.

By using both active and passive collection in conjunction, a balance can be reached between cost and a comfortable environment in a wide variety of home designs.



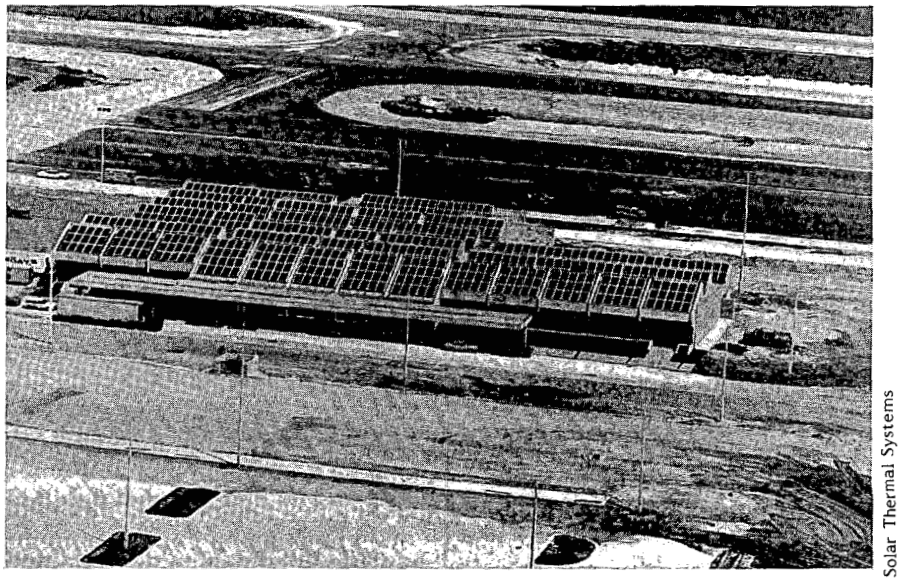
N.Y.S. Energy Research and Development Authority

This hybrid solar house has active solar collectors on the roof and passive solar collection through the glass walls, with storage mass in the floor.

The Uses of Active Solar Collectors

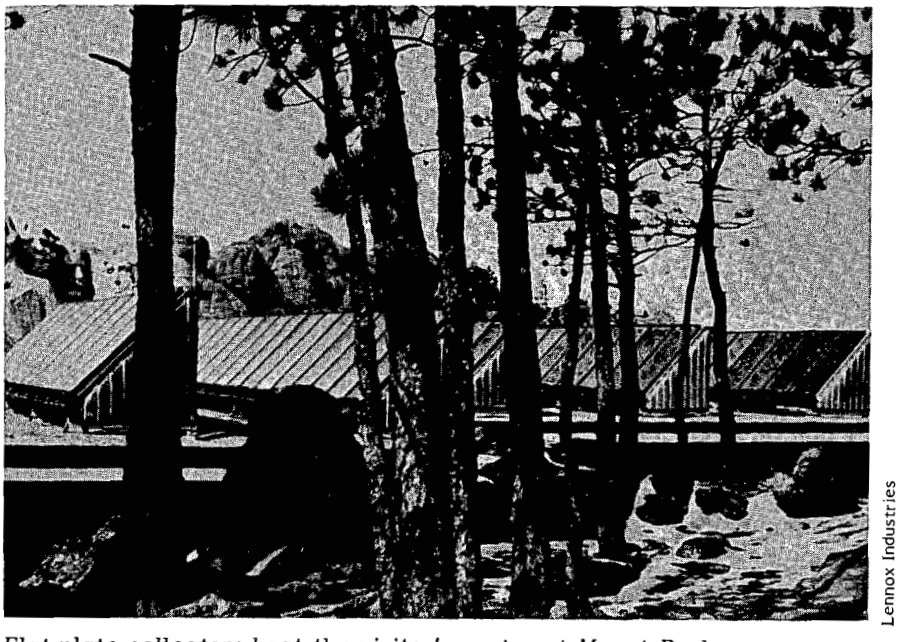
Human beings, inveterate tinkerers, have designed solar collectors to do a variety of jobs. One of the most important and practical is heating water for domestic use. Another major use of collectors is for space heating. These basic uses have been extended to include heating for industrial processes and for crop drying, heating swimming pools, and air conditioning by solar-assisted heat pumps.

solar-assisted heat pump: a heat pump that uses solar heated fluid to improve its output.



Solar Thermal Systems

Solar collectors heat and cool this airport terminal in Florida.



Lennox Industries

Flat plate collectors heat the visitor's center at Mount Rushmore.

Solar collectors have also been designed to concentrate the sun's rays, thereby attaining much higher temperatures. These higher temperatures can cook food, produce steam to generate electricity, and even melt metals. Concentrating and focussing collectors will be discussed in Chapter 16. The present chapter will deal only with the lower temperature collectors, primarily flat plate collectors, which are used mainly for domestic hot water and space heating.

The Flat Plate Collector

You may recall that a simple description of a flat plate collector was given in Chapter 4, where we compared the earth to a solar collector.

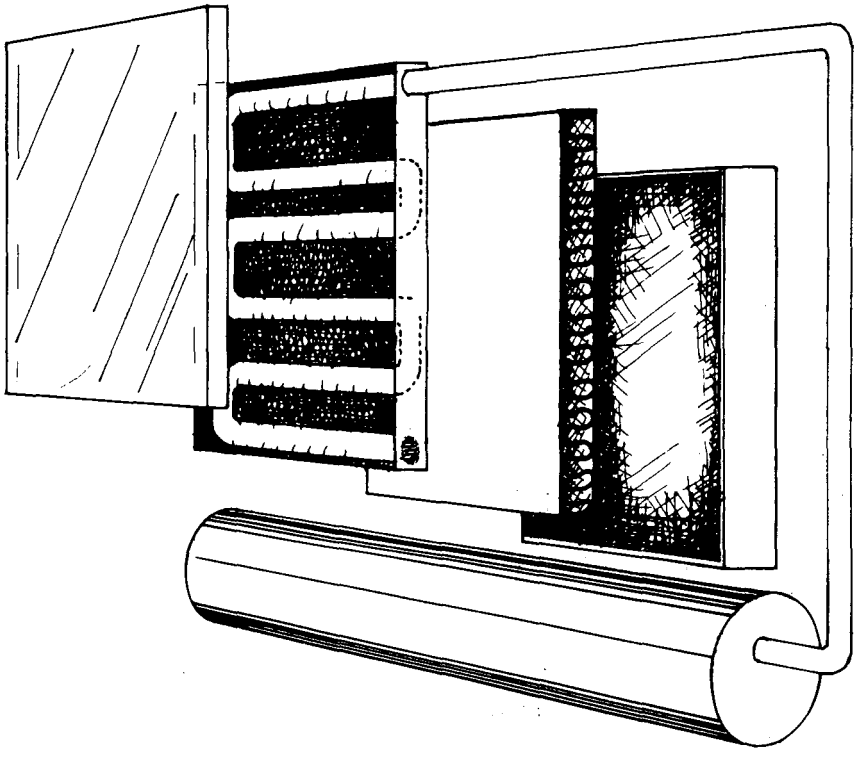
Briefly, a flat plate solar collector consists of:

a glazing - a transparent cover, which transmits visible light but blocks outgoing infrared radiation

an absorber plate - a dark surface which absorbs light and becomes heated

a transport system - a fluid which passes over the absorber plate through tubes or ducts and carries off the heat

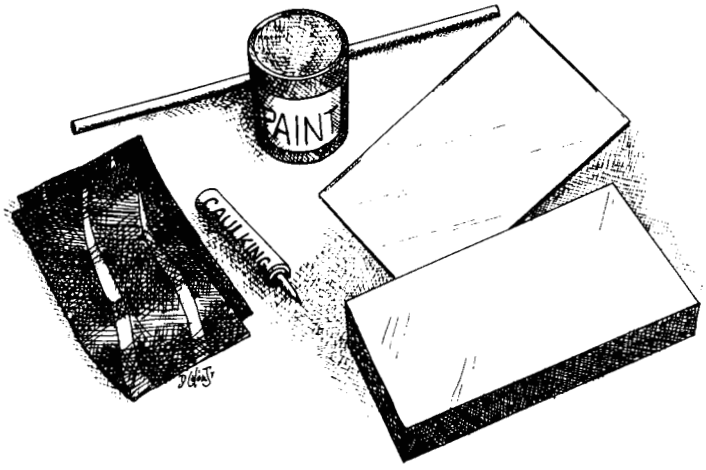
a storage system - some mass (sand, water, etc.) in which the heat carried by the transport fluid can be stored for later use.



You may also remember that a solar collector is enclosed in an insulated container to improve efficiency.

A solar collector has to have staying power to be a worthwhile investment. It has to stand up to wind and weather, temperature extremes, and long exposure to ultraviolet light. It shouldn't rust, corrode, break, leak, freeze, crack, or melt, (it's important to realize that a "stagnant" solar collector can heat to over 150°C or 300°F), and under all stresses it must do its job efficiently. Let's look at some of the materials that are used in solar collectors, and see how they compare.

stagnation: a high-temperature condition that occurs in a solar collector when the sun is shining but transfer fluid is not flowing. (See glossary.)

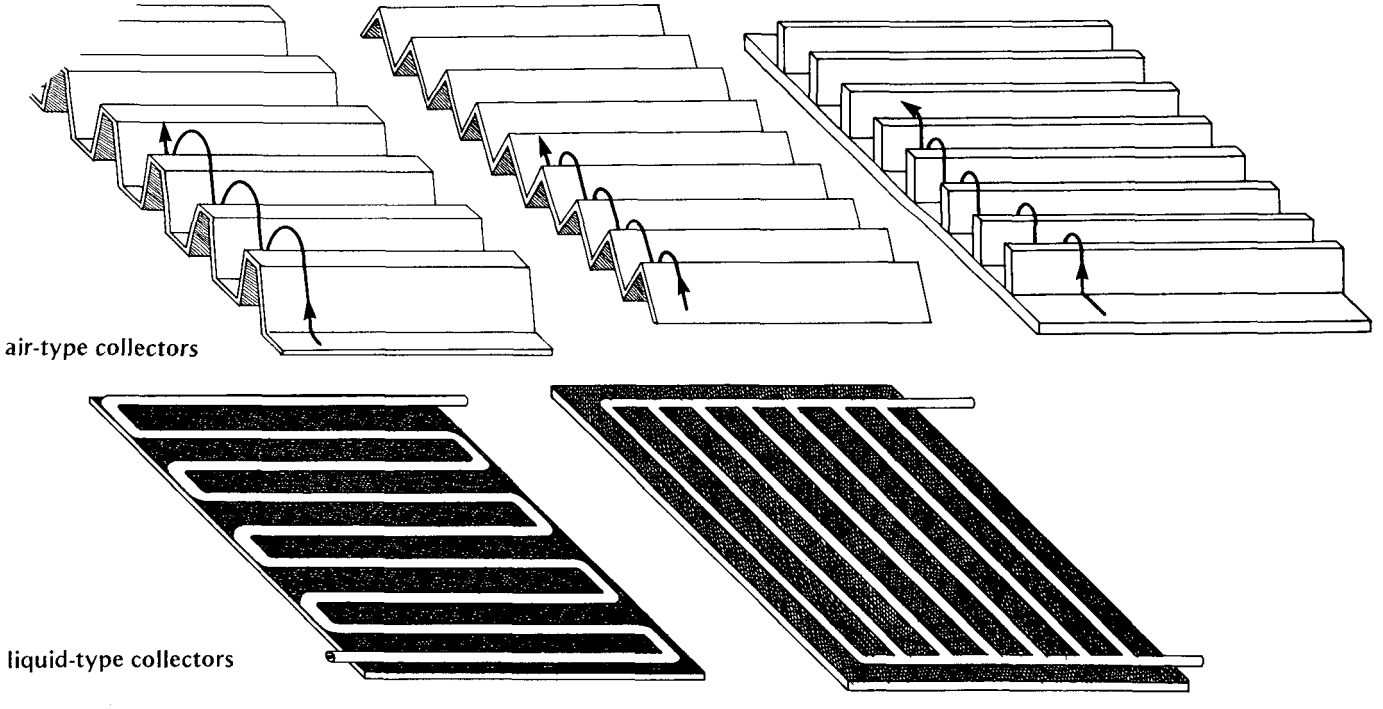


Components	Materials	Comments
Container	Metal (aluminum or galvanized steel)	Lightweight and durable.
	Fiberglass or plastic	May deteriorate rapidly due to high temperatures and ultraviolet radiation.
	Wood	May deteriorate with high temperatures and moisture condensation. Dry wood may even reach kindling point.
Container paint	Paint or wood-preserving stain	Only outside of container should be painted.
Hardware	Galvanized nails or water-proof fasteners	Long-lasting, won't corrode.
Caulking	Silicone, urethane (high temperature type)	Long-lasting, good thermal resistance, urethane somewhat easier to work with.
Insulation (4 inches recommended)	Fiber glass (blanket-type)	Has relatively high insulating value, stable.
	Fiber glass (rigid, "duct-type")	Recommended for directly under absorber plate.
	Foam insulations	Not recommended. Burn or melt at high temperatures.
Absorber Plate	Copper	Best conductor, resists corrosion.
	Aluminum	Cheaper, good conductor, will corrode in contact with other metals or moisture.
	Steel (galvanized)	Good conductor, may rust, harder to bend for shaping.

Components	Materials	Comments
Transport System (usually the same material as the absorber plate)	Copper	Best conductor, resists corrosion, can be used with potable water or treated water.
	Aluminum	Good conductor, corrodes with antifreeze or water.
	Steel	Good conductor, can only be used with antifreeze; corrodes with water.
	Plastic (polybutylene or chlorinated polyvinyl chloride)	Inexpensive, poor conductor, recommended for low temperature use such as pool heating.
Absorber Plate Coating	High-carbon flat black paint	Must be flat black, rated for very high temperature use.
	Black chrome, nickel, or copper oxide	Must be commercially applied, expensive, but very efficient due to high absorption and low emission of radiation.
Glazing	Glass	Probably best, but expensive and breakable. Low-iron glass with antireflecting coating has best transmittance of high-energy radiation and doesn't reradiate infrared. In cold climates double glazing with 1" air space is recommended.
	Hard plastics (plexiglass, vinyl)	Inexpensive, but bend and warp if heated, and may discolor with exposure to sunlight.
	Plastic films:	
	Polyethylene	Cheap, poor transmittance, degrades rapidly.
	Mylar & Tedlar	Cheap, fair transmittance but both reradiate infrared; Mylar degrades, Tedlar shrinks.
	Teflon	Expensive, excellent transmittance, very thin so can only be used for inner glazing.
	Reinforced polyesters (Filon, Glassteel, Kalwall)	Tough, good transmittance, easy to work with.

Collector Design

When it comes to assembling all of these materials to make an efficient collector, there are some important points to keep in mind. One is the design of the absorber plate. It would be impossible to cover all the absorber plate designs in use. Most air-type collectors, for example, have no pipes or tubes. The collector plate is corrugated metal or screening, sometimes with perforations or baffles, and the air flows over, under, or through the absorber. The Thomason "trickle" collector simply has water flowing from the high end of the collector down open channels in the absorber to a catch gutter at the low end. Some absorber plates avoid the need for pipes by having a corrugated sheet bonded to a flat plate. The corrugations serve as pipes.

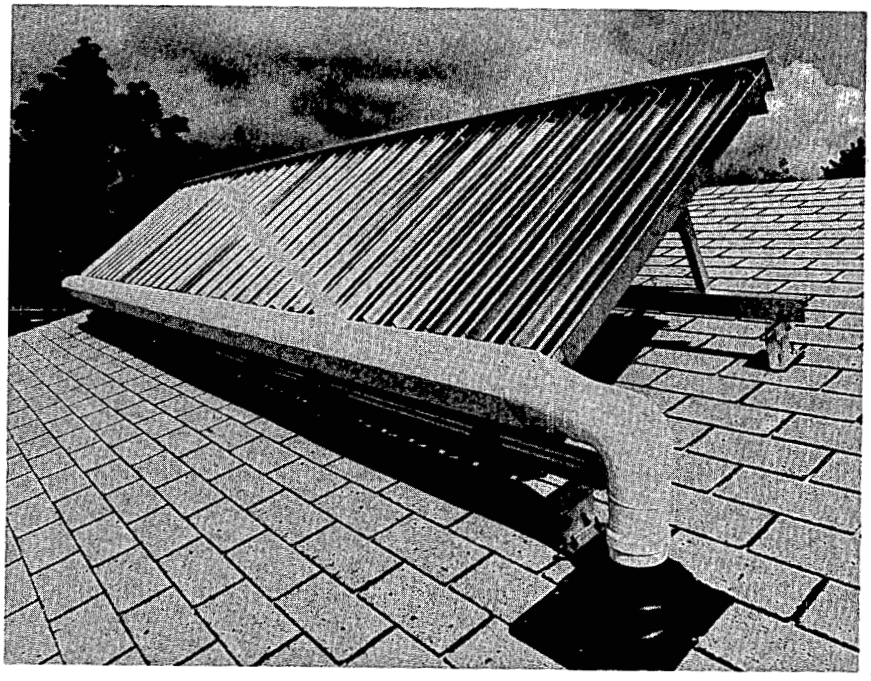


Flat plate collector absorber plates

However the absorber plate is designed, the designer has to keep in mind the efficient circulation of fluid through the collector. Four to six inches is recommended as the best spacing for the channels. The design should take advantage of natural thermosiphoning. That is, the intake for cold fluid should be at the lower end, and the outlet for heated fluid, at the upper end.

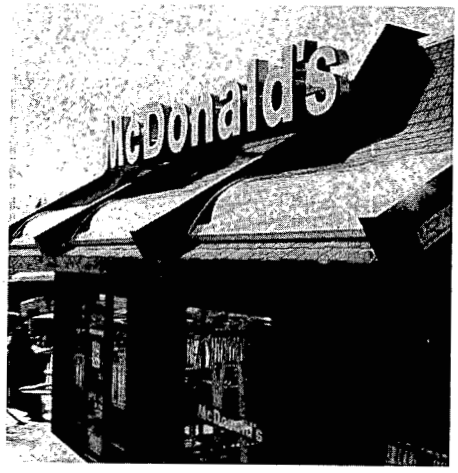
There are a few contingencies that need to be planned for. Some condensation is bound to form inside the collector, fogging the glazing. For this, there should be a drain hole. There should also be small vents or valves in the system near the upper and lower ends of the collector to allow venting and avoid overheating in case the fluid stops circulating for some reason.

Conservation is just as important with active solar as with passive. If a collector is poorly caulked and insulated or has a glazing that lets large amounts of radiation escape, it can't operate efficiently.



Sunmaster Corporation

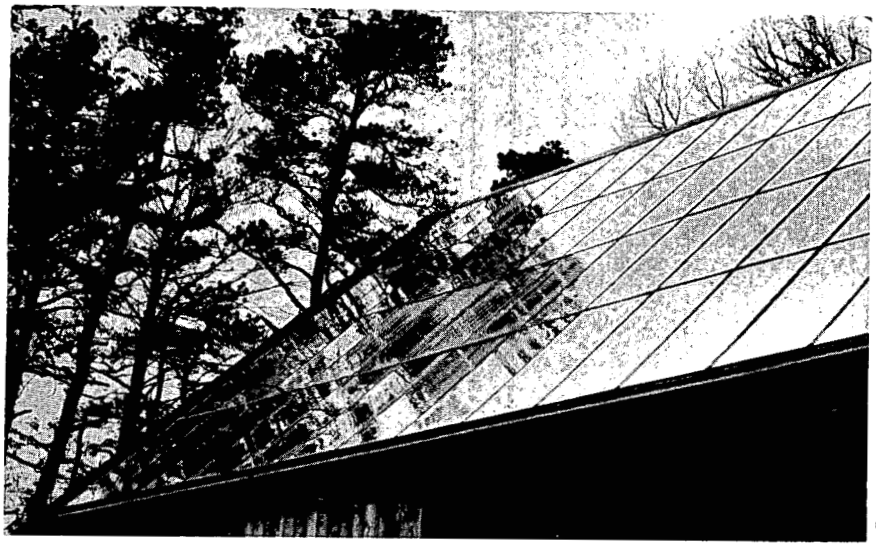
In this evacuated tube collector each absorber pipe is surrounded by a glass vacuum tube to prevent heat loss and give high efficiency.



Not all solar collectors follow the simple flat plate design. These have a bowed glazing to improve efficiency.

Size

The size of your array of collectors depends on whether you plan to use them for water heating or for space heating. To provide at least 50% of the domestic hot water for a family of four, sizing recommendations range from 60 to 80 square feet, depending on climate. For space heating, estimates are based on square feet of living space rather than number of persons, and also have to take into account the local climate. A very rough rule of thumb would be one square foot of collector for every two to three square feet of living space.



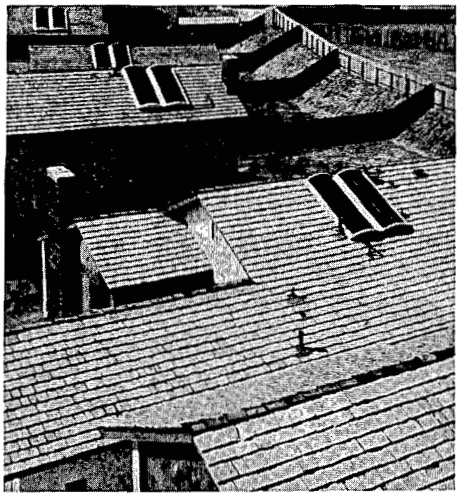
R. A. Fogarty

Solar Ponds

A pond of water, if properly designed, makes a very good large-scale collector. Water is a good solar collector and heat storage medium because of its high heat capacity, and its transparency, which permits deep penetration by solar radiation. A variety of designs for "solar ponds" have attempted to take advantage of these qualities.

Typically, a solar pond will have a black bottom to improve absorption. Brine is fed into the bottom, giving the lower water greater density and reducing convection. Upper, less dense water acts like a transparent insulator, admitting radiation but blocking heat loss. Transfer fluid is circulated through pipes in the bottom of the pond to transport heat to the area of use.

The Active Solar System



Grumman Energy Systems, Inc.

There are many types of successful active collector systems. Some use liquid, some, air as their transport medium. Some feed directly into the heating system or household water supply, while others transmit their heat to another medium through a heat exchanger. One system may store heat in a insulated water tank, another, in a bed of sand. Most use thermostats and timers to control circulation and storage. These aspects of the total active solar system will be discussed in the next chapter. In Chapter 15 we will look at system efficiency and costs.

The solar collector is making its appearance on many a roof and lawn. More than 2,000,000 have been installed in Japan, and solar water heaters are now required on new buildings in parts of Australia.

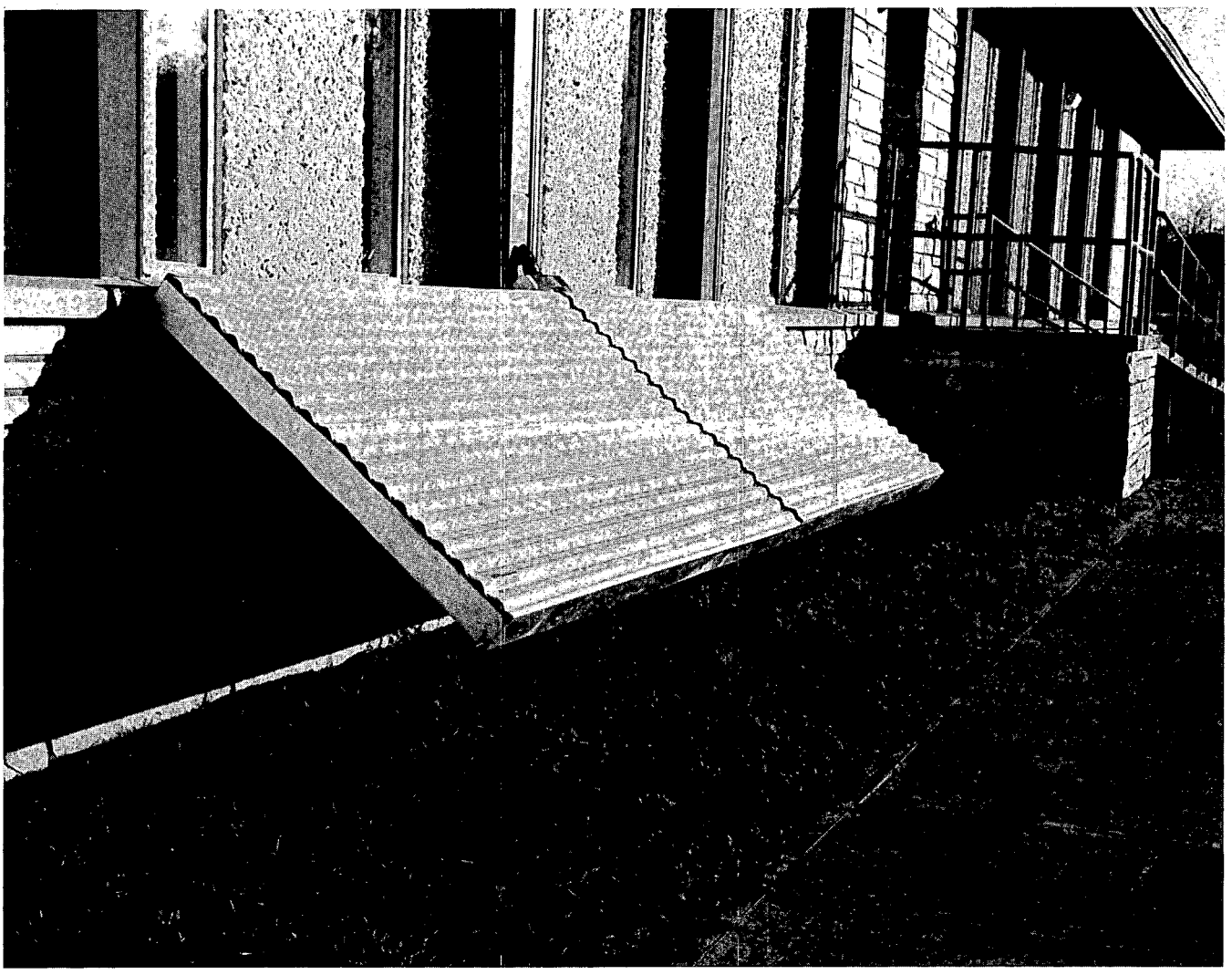
But the collector itself is only the tip of the iceberg. Just as there is a lot more to solar energy than its most visible technologies, there is a lot more to an active solar system than the collectors.

Chapter 14

Moving and Storing Sunshine

Most solar collectors look basically similar, but in an active solar system there's more than meets the eye. It's when we go beyond the collector to the transport and storage apparatus that we see how varied the systems are - and how varied are their uses. What are some of those uses?

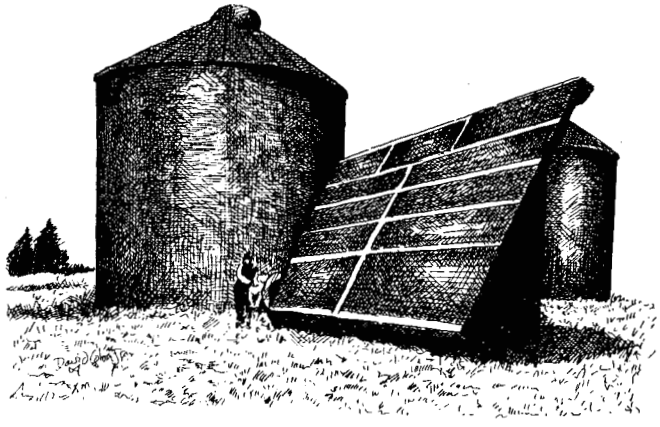
When people see solar collectors they tend to think of space heating. But actually the most popular and widespread use of solar collectors is for domestic water heating. Swimming pools are also heated using lower temperature plastic collectors.



Advance Energy Technology

These collectors provide domestic hot water for a town hall in northeastern New York.

Often forgotten are the many industrial and agricultural uses for active solar collectors. Dyeing, washing, drying, evaporating, shrinking, curing, sterilizing -- the processes that require hot water or air are numerous, and many farmers and manufacturers are using solar energy to meet the need. Even when very high temperatures are needed, the use of solar energy for preheating can save significant amounts of fossil fuel.

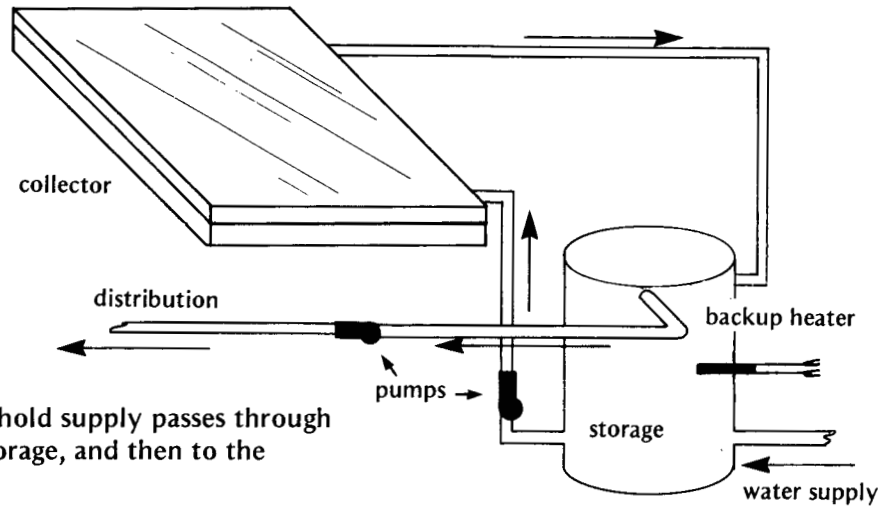


From this introduction it should be obvious that the design of a solar system must be tailored to its end use. Let's look at the basics of an active solar system before we go into the choices involved in designing an individual system.

The Overall System

Starting where energy enters the system, we have the collectors, mounted at the best angle for efficient solar collection. Passing through the collectors is a fluid, air or liquid, which picks up heat from the absorber plate. This fluid is moved by forced convection with fans or pumps. (If the system uses natural convection, it is a passive, thermosiphoning system, not an active system.)

thermosiphoning: currents resulting from the natural fall of denser, cooler fluid displacing lighter, warmer fluid.



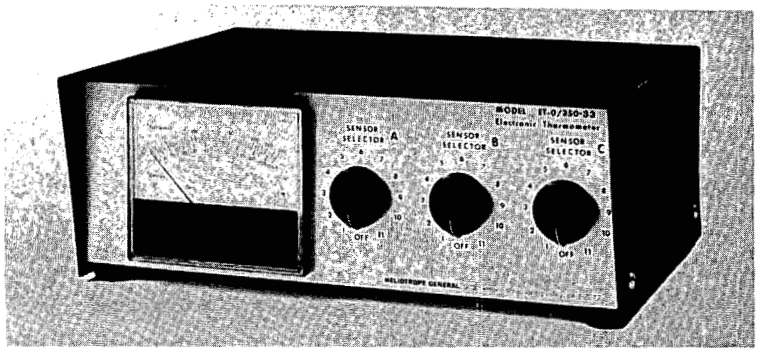
Water from the household supply passes through the collectors, into storage, and then to the point of use.

Forced convection may carry the heated fluid directly to the point of use. More commonly, it is transported to a storage container, insulated to hold heat which will be drawn on later. The storage material may be water, sand, crushed rock, or phase-change material. Heat can be drawn from storage long after it is placed there. Often a backup system of coal, oil, wood, or electric heat feeds into the same storage, operating if the storage becomes too cool when there is no sunlight.

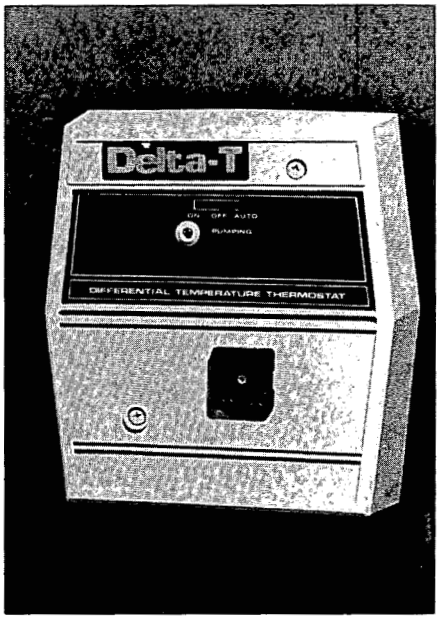
phase-change material: substance that can be used to store heat through melting or evaporation. (See "latent heat storage": glossary.)

backup system: energy system using conventional fuel to supplement a solar energy system. (See glossary.)

This very simple explanation ignores the vents and drains, expansion tanks, pressure relief valves, differential thermostats and sensors, and other plumbing details that make the system run properly. One item that can't be ignored, however, is the heat exchanger.



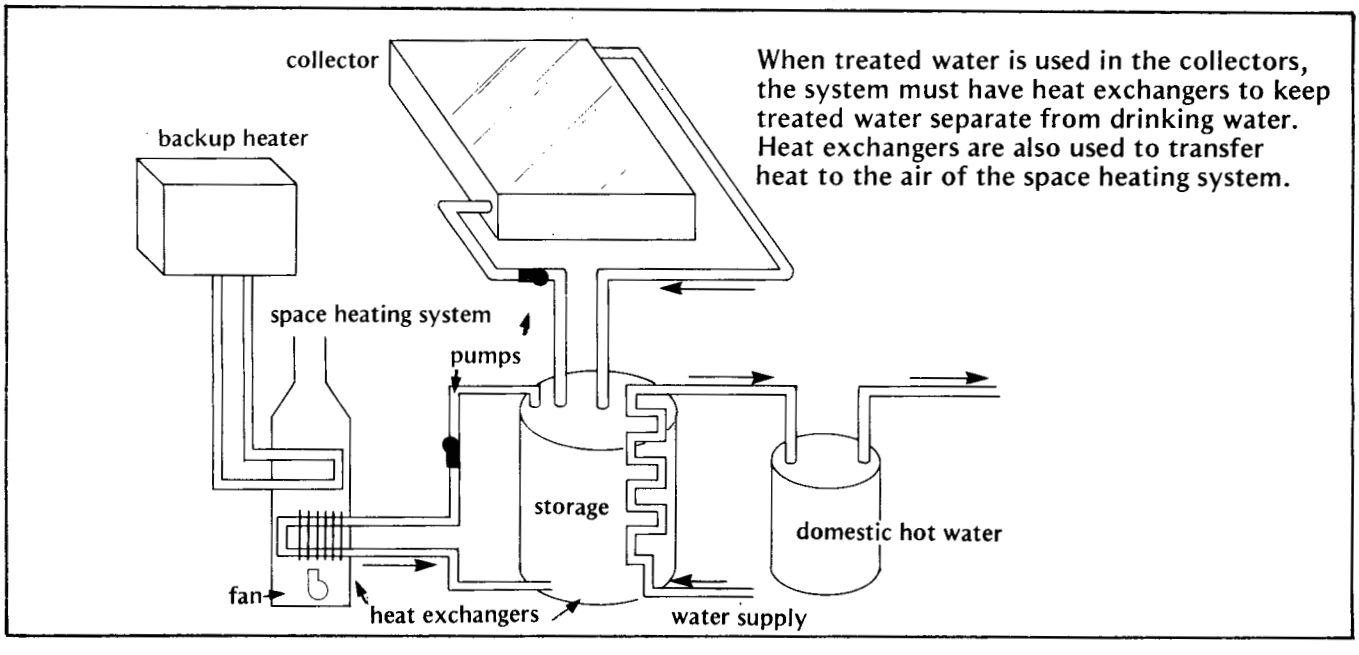
Heliotrope General



Heliotrope General

Heat Exchange

Imagine that you want to transfer heat from one fluid to another as completely and efficiently as possible, without allowing the two to touch. Of course, you'd put a good conductor between them, letting them both touch the conductor. The more shared surface, the better. That's what a heat exchanger is. You use it whenever you want to isolate the collector fluid from the end-use fluid. If the water in your collector contains antifreeze, you don't want it to mix with the water that comes out of your tap. A heat exchanger



When treated water is used in the collectors, the system must have heat exchangers to keep treated water separate from drinking water. Heat exchangers are also used to transfer heat to the air of the space heating system.

will run one fluid via metal pipes or fins through a container of the other fluid. (Copper tubing is preferred, for its high conductance.) The metal conducts, and heat is exchanged, without any mixing of fluids. A heat exchanger goes in the storage container of an active solar system.

Now that we have a general picture of an active system, let's examine some of the choices involved in selecting or building such a system.

Transfer Fluids

Air, water, treater water, or phase-change fluids: those are the choices for transfer fluids. Each has advantages and disadvantages.

Air

Air systems are easiest to build, and air is certainly cheap! It's apt to leak, but air leaks aren't damaging, although they reduce efficiency. An air system won't have freezing, boiling, or pressure problems. Such a system is rather bulky because of the large ducts and storage mass required. It's best for space heating in a house with a forced air system, where no heat exchanger is necessary because the collector air can mix with house air. Air doesn't transfer heat very well, so it's not the best fluid for use with a heat exchanger to heat water.

Water

With its higher heat capacity, water is a more efficient transfer fluid by volume than air. Therefore its transport system (pipes) is less bulky than the transport system for air (ducts). However, corrosion, freezing, and leaks all have to be considered. The collectors in a water system have to be designed to drain down in sub-freezing temperatures to prevent burst pipes; hence controls are more complicated. A system that contains pure water can connect directly with the domestic water supply and the house radiators.

Treated Water

Some of the drawbacks of a water system can be cured with additives: buffers to reduce corrosion and antifreeze to allow the system to function in the coldest weather. Such additives, in their turn, have advantages and disadvantages. A system with buffers and antifreeze will last longer and doesn't require a "draindown" component. However, the additives are expensive and may be toxic. A system containing them must have a double-thickness heat exchanger to prevent pollution of the tap water.

National Solar Heating and Cooling Information Center

Drains, fill points, and pipes carrying treated water should be labeled.

buffer: additive to a transfer fluid to prevent corrosion.

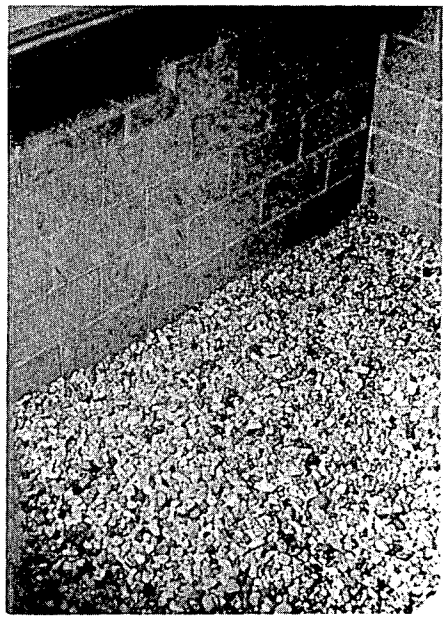
draindown: component which drains an active system when necessary to prevent freezing. (See glossary.)

One additional advantage of both water and treated water is that the high efficiencies achieved in those systems allow them to be used for cooling as well as heating. The solar-assisted heat pump uses high-temperature water to aid in the air-conditioning process that extracts heat from within the house and dumps it outside.

Phase Change Transfer Fluids

Substances like liquid freon and sulfur dioxide have also been used in active solar systems. These store heat by a "phase change"; that is, they evaporate at fairly low collector temperatures, storing large amounts of heat. When they reach the cooler storage area they condense, releasing that heat into the storage material. Phase-change transfer fluids can give a system high efficiency, but they too have disadvantages: expense and, in some cases the real possibility of high gas pressures and toxic gas leaks.

After choosing a transfer fluid the logical next step is to choose a storage material, because the first choice will, to some extent, dictate the second.



National Solar Heating and Cooling Information Center

Rock storage is usually used with air-type solar collectors.

Storage Materials

As with the transfer fluid, the purpose of the system must be considered in choosing a storage material. Space and expense, as well as convenience in drawing heat from storage, are all factors in the decision.

Rock: Pebbles and Gravel

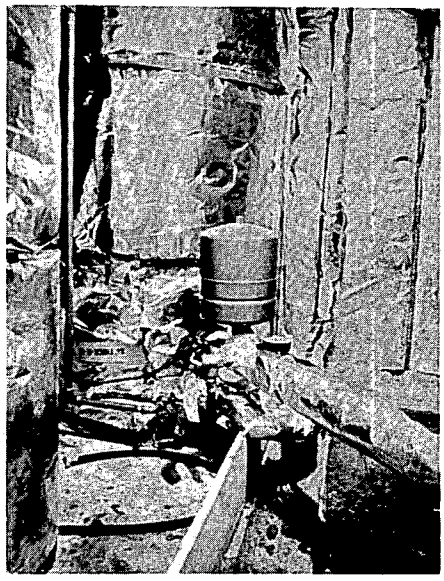
Non-corrosive and relatively inexpensive, rock storage has long been popular for forced air systems. The air passes directly through the rock or gravel bed. Since rock has only average heat storage capacity, a large volume is required to do an adequate job. The rock must be clean. Even with cleaning some owners have encountered serious problems with mildew building up in the storage area when cooling allows condensation.

Sand

Sand has the advantages of rock, and can be used for an air or liquid system. If a sand bed is used, ducts or pipes are laid throughout the bed to effect heat transfer.

Water

Cheapest of the storage materials, water also has an excellent heat capacity which allows for more compact storage. It can cause corrosion, however, so that ultimately water storage may be more expensive than, say, sand. Water storage is used most effectively with liquid transfer fluids.



National Solar Heating and Cooling Information Center

Pipes and storage should be well insulated to get the most from the system.

Phase Change Materials

You may recall our discussion of latent heat from an earlier chapter. Although a substance can store thermal energy as sensible heat that can be measured with a thermometer, it can store far more thermal energy by "changing its phase" from solid to liquid or liquid to gas. The stored energy is latent heat, not detectable by measuring temperature, but nonetheless there.

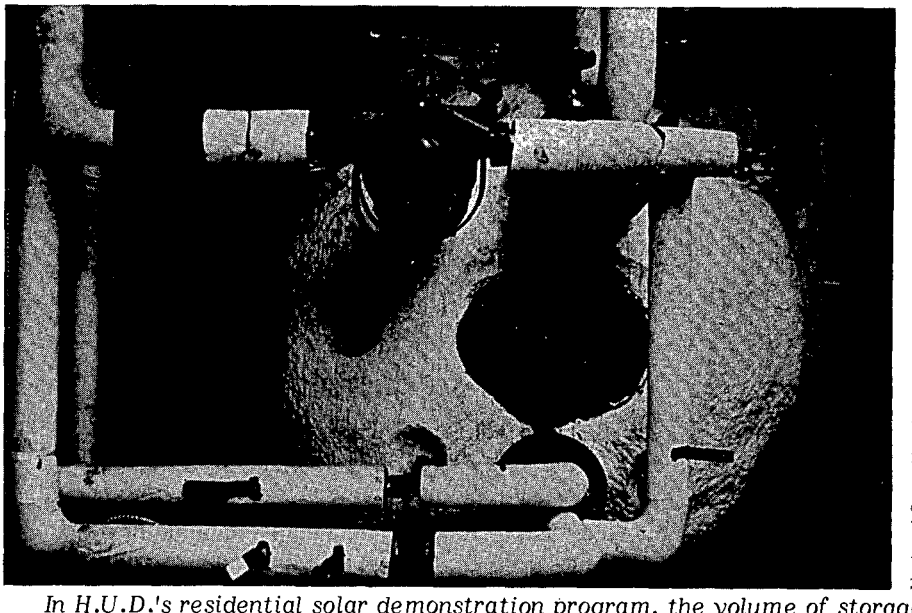
Some of the most interesting work in solar energy storage is being done with materials that change their phase from solid to liquid at temperatures easily attainable with solar collectors or even with passive solar design.

A good example is Glauber's salt (sodium sulfate decahydrate) which melts at 32°C (89°F). The heat which these salts can store during a phase change makes them about five times as efficient in absorbing heat as the same volume of water (at that temperature range).

The weakness of phase-change materials is that they cost more than commonplace storage materials, and eventually have to be replaced because they lose their capacity to store heat. Container corrosion is also a problem. However, there are presently a number of research efforts directed at solving these problems.

Sizing the Storage

In the last chapter we discussed the appropriate collector area for space heating and water heating. Storage size is usually geared to collector size, and as with collector size, recommendations vary. For space heating with water storage, recommendations range from 60 to 120 liters of water for every square meter of collector surface (2 to 4 gallons per square foot). For space heating with rock or sand



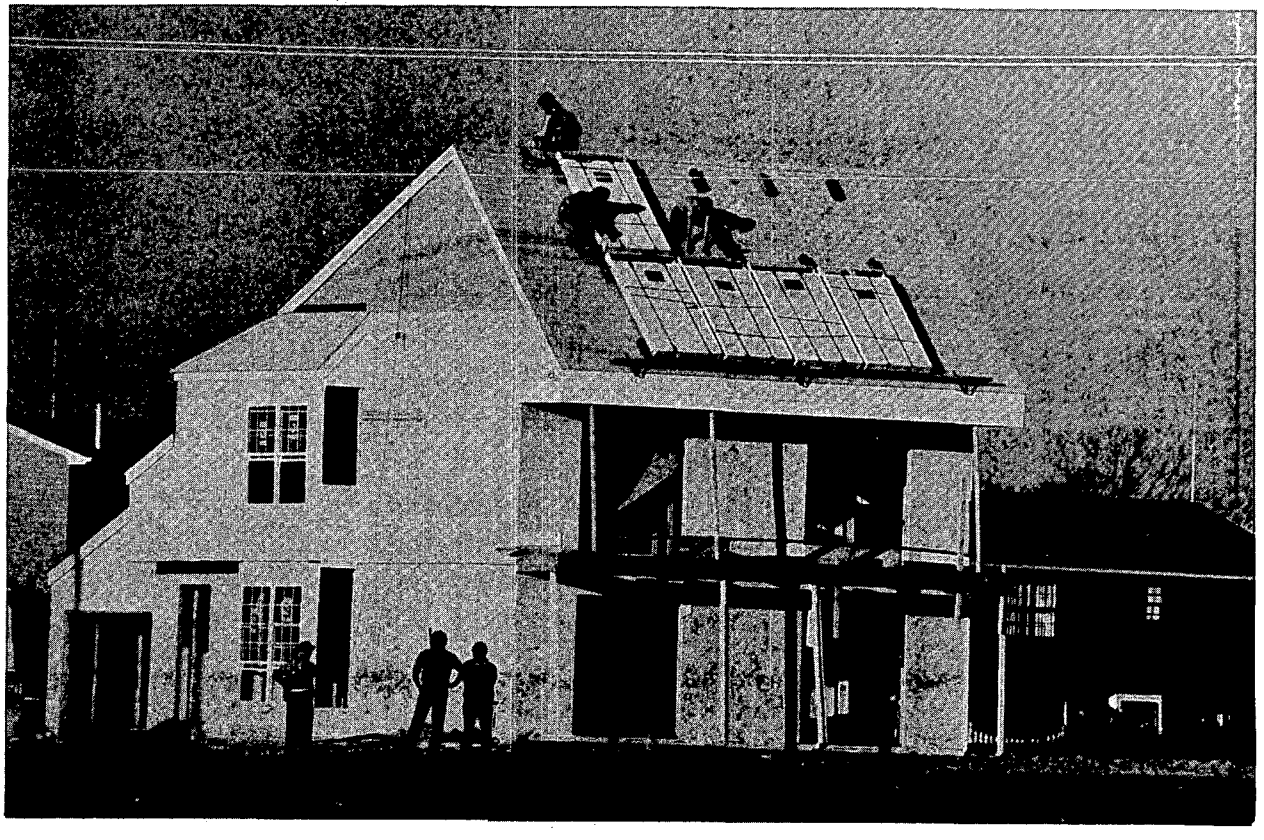
National Solar Heating and Cooling Information Center

In H.U.D.'s residential solar demonstration program, the volume of storage for space heating systems averaged 2 gallons of water per square foot of collector in liquid systems, and 1 cubic foot of rock per square foot of collector in air systems.

storage, 500 to 900 kilograms per square meter of collector (100 to 200 pounds per square foot) is suggested.

Although these masses may sound large, it's known that a large storage mass, storing a large amount of heat at a fairly low temperature, will make a system work more efficiently and give more even temperature and longer back-up for cold nights and cloudy days than a small storage mass.

The exception to this is the storage tank for domestic hot water. If you make this storage too big, you may have a whole lot of very lukewarm water, instead of just enough nice, hot water. Figure on 75 liters (20 gallons) per person per day. If you want to save for a cloudy day, you might want to plan on twice that per person. But a 450 liter (120 gallon) tank would be the maximum desirable.



Solar Thermal Systems

Know Your System

Read on. The next chapter will discuss system operation and efficiency. We'll also take a brief look at costs and questions of safety.

As with all solar technologies, an active solar system requires knowledge in the owner and user. But active solar has refinements that can't be thoroughly discussed here. The bibliography for this chapter may be helpful to anyone who plans to make active use of the sun.

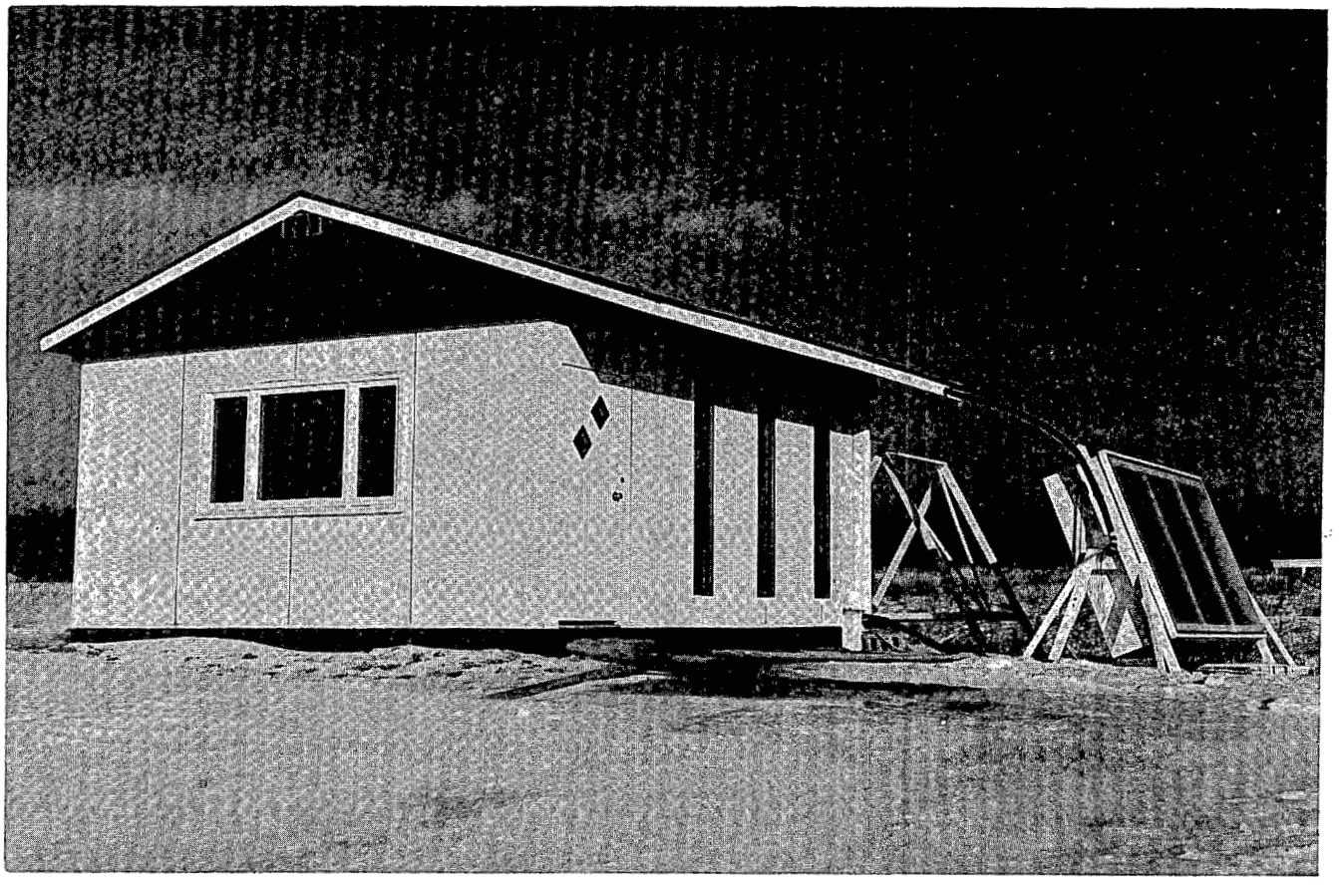
Chapter 15

Your Own Solar System

Chapters 8 and 9 discussed the "personal solar budget," the amount of insolation that a given site receives on an annual average. One fact is clear: the personal budget of insolation varies. The changing seasons and weather cause fluctuations in our solar income from day to day.

collector efficiency: fraction of incoming radiation that is captured as heat. (See glossary.)

For this reason the designers of solar collectors have always been interested in collector efficiency. They have attempted to build devices that would collect and store the most solar energy possible under cold, windy, or even cloudy conditions. Here are some things they have learned about making efficient active solar systems.



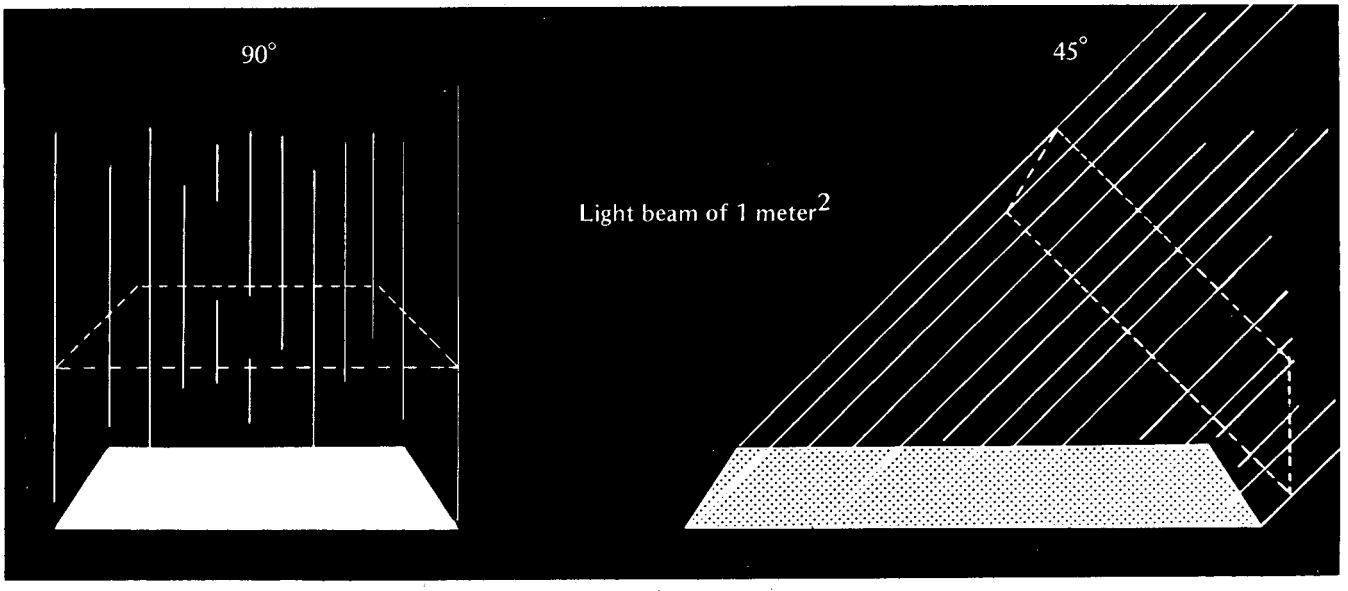
SUNY Atmospheric Sciences Research Center

This well-insulated experimental building in New York gets all its heat from direct gain and its solar collector. In a winter of testing the interior temperature never fell below 58°F.

Factors Affecting Collector Efficiency

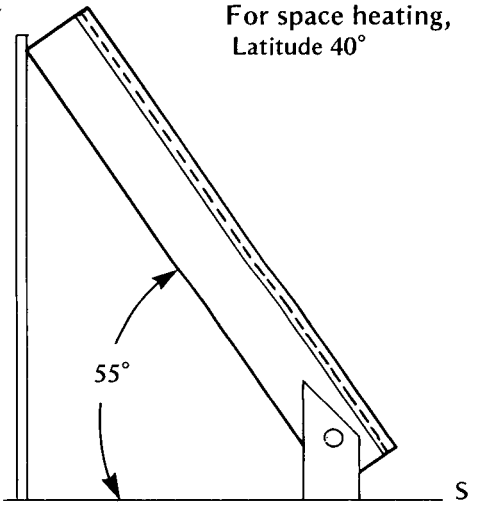
Orientation

One important efficiency factor is collector orientation. It should be obvious that if the sunlight falls at a 90° angle on the collector there is more energy per unit area and less reflection than at any other angle.

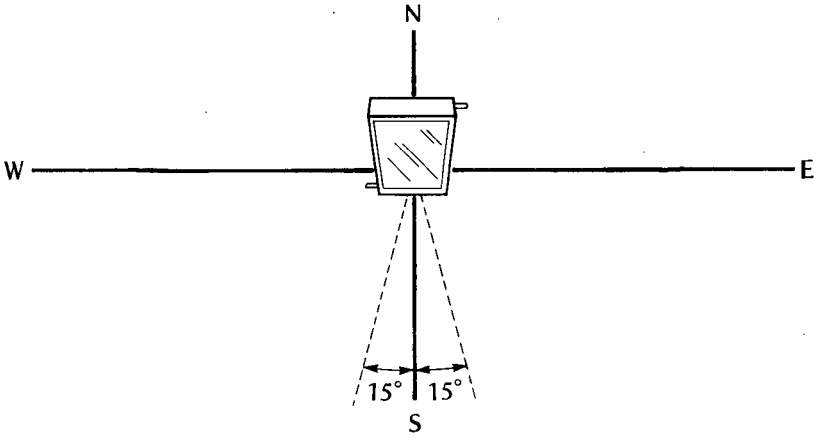


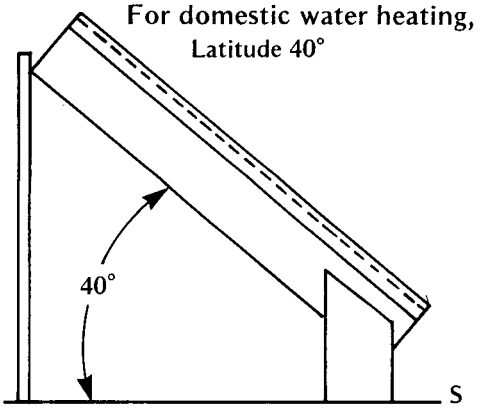
The effect of beam angle

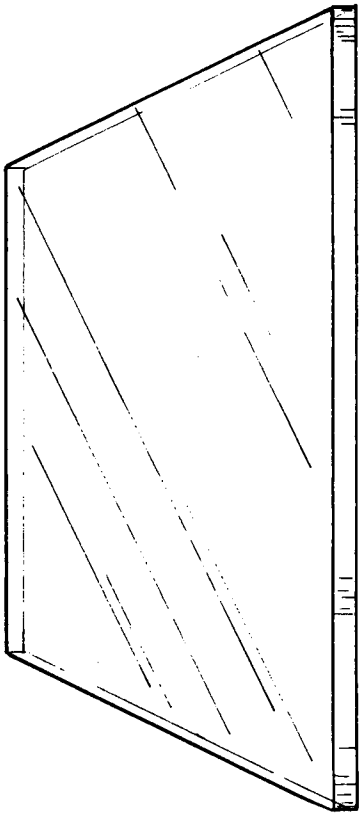
An unobstructed, south-facing location is best. In determining collector angle, consider what time of year the most radiation will be needed. With space heating, the important time is winter, and the recommended angle is the latitude plus 15°. The collector, at this rather steep angle, catches the low winter sunlight directly. But if the collectors are also to be used in summer to assist in air conditioning, the angle should be latitude plus only 5°. Domestic hot water is needed all year. So the recommended angle for these collectors is approximately the same as the latitude, since that angle will receive the most radiation on an annual average.



These recommendations are not hard and fast, however. Research shows that a difference of 15° in collector tilt makes a difference of less than 5% in efficiency. Likewise, if the collector is oriented to within 15° east or west of true south, the loss of efficiency is slight.





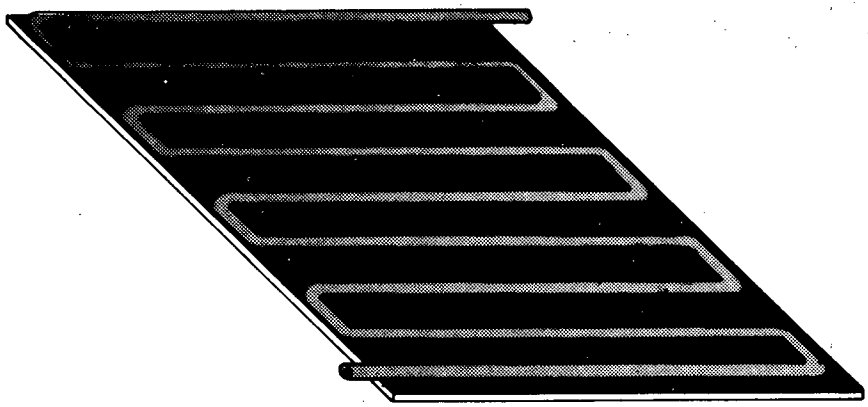


Materials

Glass, especially low-iron glass, is probably still the most efficient glazing, because it is most transparent to solar energy. Most collector tests show higher efficiency for double glazing than for single, especially in colder weather. The loss of incoming radiation from double glazing is more than compensated for by the value of the second layer in blocking escaping heat. However, for low-temperature applications like swimming pool heating, single glazing may be preferred.

Glazing efficiency can be further improved by applying an antireflective coating to the outside surface of the glazing. By mounting the glazing within four centimeters of the absorber plate, you can reduce energy losses caused by the convection of heated air away from the plate.

Although any metal plate coated with flat black paint is a good absorber, it is also a good radiator. So efforts have been made to find a way of coating metal to prevent the reradiation of infrared. A surface that absorbs solar energy well but emits very little infrared radiation is called a "selective surface."



A selective surface is generally some metal oxide deposited electrically on a bright metal absorber plate. At high temperatures a selective surface absorber with just one glazing performs better than a flat black absorber, even with double glazing.

Liquid is preferred to air as a transport fluid from an efficiency standpoint. It has a higher heat capacity, and more heat can be transferred per unit of electric power by pumping liquid than by blowing air.

Insulation and tightness are also efficiency factors. Every leak, whether of fluid or of heat itself, is a drain on the collector's efficiency.

Double glazing, selective surfaces, and watertight plumbing all add to the cost of a collector system. In making choices of materials for a collector, therefore, efficiency has to be balanced against cost.

Operation

To operate at greatest efficiency, a system must be designed to take advantage of the most possible insolation. The basic rule for efficient collector operation is this: The closer the collector temperature stays to the ambient air temperature, the more efficiently the collector operates.

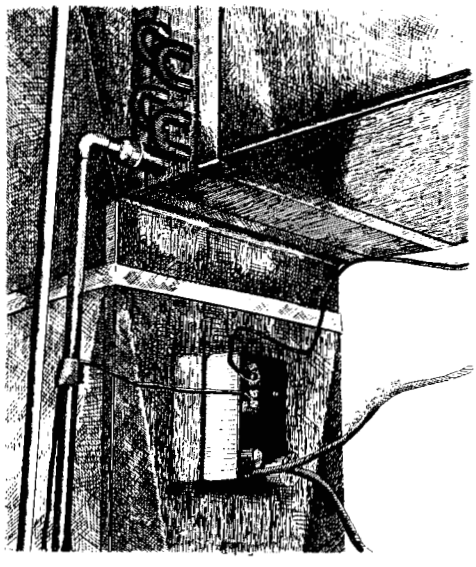
ambient air temperature: temperature of air around the collector.

Why is this? Isn't the whole purpose of a solar collector to collect radiant energy? And shouldn't a successful collector, therefore, get much hotter than the surrounding air?

The answer is that although the purpose of the collector is to collect energy and transform it to heat, the purpose of the system is to move the heat and store it, not leave it to build up in the collector. If the transport fluid is flowing too slowly, the collector overheats and begins reradiating energy to the surrounding air. If the system is maintaining the proper flow rate for the transport fluid, the fluid will be removing energy as fast as the collector collects it. So the collector should never get extremely hot, and won't do so unless the system shuts down.

Controls

The thermostats, pumps, and fans on an active system allow the system to collect and store energy at appropriate times, but they also protect the system from freezing or overheating, which can damage or destroy the collector.



Essentially, the controls must allow the system to collect energy when there is energy to collect, and must shut down the system when continued operation would mean energy loss. In other words, fluid must begin to circulate when the collector reaches its start-up temperature. If the collector drops below its cut-off temperature the system should stop until the collector heats up again. Otherwise the storage will be heating the collector instead of the other way around. Within the temperature range where collection is possible, the rate of flow should be accelerated or slowed to collect as much energy as possible. With a properly controlled flow rate the collector remains at the temperature which will provide the desired fluid temperature at the best efficiency.

There are other more subtle considerations in designing the controls for an active solar system. A well-trained installer or salesman should be aware of how controls may need to be tailored to a particular location or climate.

How Collector Efficiency Is Measured

The National Bureau of Standards and the American Society of Heating, Refrigerating, and Air-Conditioning Engineers have developed procedures to test collectors for efficiency, and most major manufacturers can provide independent test results to a prospective buyer.

Collector efficiency is defined as the ratio between the energy collected and the solar energy incident upon the collector. This efficiency is a function of insolation, outside air temperature, absorber temperature, type of transport fluid and flow rate.

$$\text{\% collector efficiency} = \frac{\text{heat collected}}{\text{solar energy incident on collector}} \times 100$$

$$\eta = \frac{Q}{I} \times 100$$

heat collected = flow rate x time x heat capacity of fluid x temperature change from inlet to outlet

$$Q = F \times t \times C \times \Delta T$$

$$Q = F \times t \times C \times (T_o - T_i)$$

To determine the solar energy incident on the collector, we use the following equation:

incident energy: amount of solar radiation falling upon a surface.

incident energy = collector area x time x insolation reading at the collector angle

$$I = A \times t \times H$$

So the complete equation for determining collector efficiency is:

$$\eta = \frac{F \times t \times C \times (T_o - T_i)}{A \times t \times H} \times 100$$

Notice that the time factors in the numerator and the denominator can cancel each other.

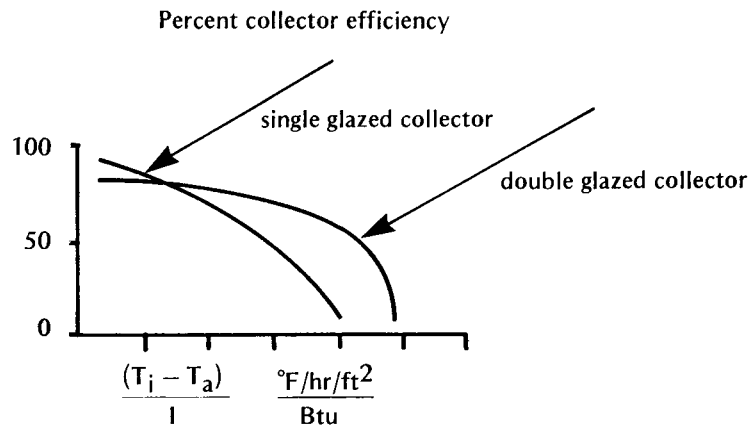
It is important, in carrying out these calculations, to be sure that the units are consistent; metric and English units can't be mixed. If necessary, insolation units are converted to be consistent with the rest of the equation.

Graphing Collector Efficiency

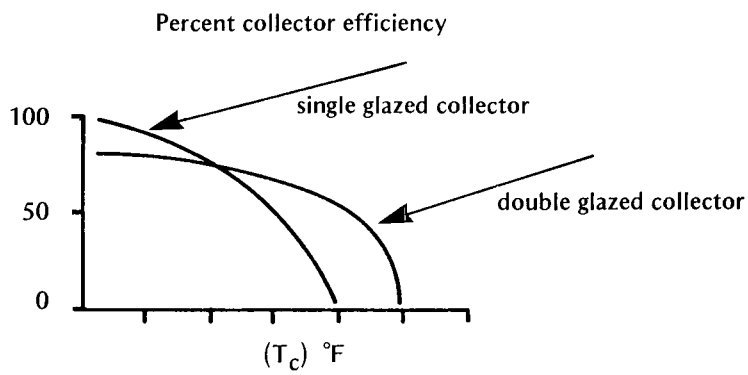
When you look at sales literature about a manufactured collector, you will notice that the literature usually includes a graph showing an efficiency curve for the collector. This curve may be plotted in one of several ways.

One way is to show efficiency versus the parameter

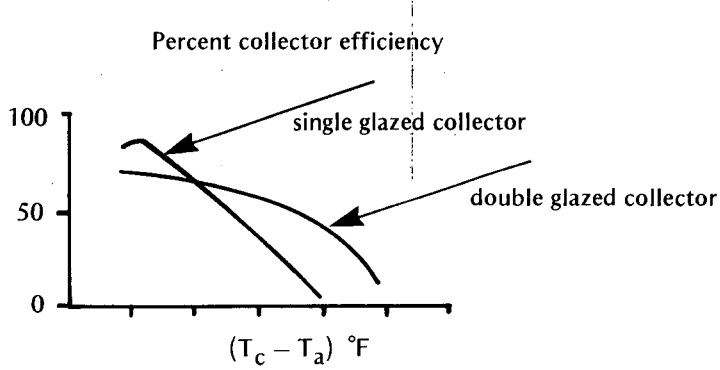
$$\frac{\text{inlet temperature minus ambient temperature}}{\text{solar energy incident on the collector}}$$



Since the meaning of this plot is not easy to picture, another way of plotting efficiency is to show efficiency versus average collector fluid temperature, which is taken to be the average of the inlet and the outlet temperatures. This type of graph might appear like this:



Another useful type of graph is the type that makes a comparison between ambient air temperature and absorber plate temperature. Since every test of a collector is done at some ambient temperature, and since the difference between collector temperature and ambient temperature is important to efficiency, graphs like the one below are especially meaningful.



Each of the factors discussed has an effect on efficiency. To make the most of an active solar system, the user will find it helpful to know how the glazing, absorber surface, insulation, fluid and flow rate, incident radiation, ambient temperature, and system controls all interact.

The Heat Pump

A heat pump is a device that moves heat mechanically from one place to another, while raising the temperature of the heat-carrying substance. The key to its functioning is the evaporation/condensation behavior of certain fluids such as freon.

By means of an expansion valve, the fluid is evaporated at one location, drawing in heat. The vapor is then circulated to the place where heat is needed, where compression and condensation of the vapor to liquid cause it to give up heat. By this means heat can be extracted from a relatively cool environment and moved to a warm one. Refrigerators and air-conditioners are heat pumps, and the same principle can be used to extract heat from cold winter air, or from a pond or sand pit, and bring it into the living space.

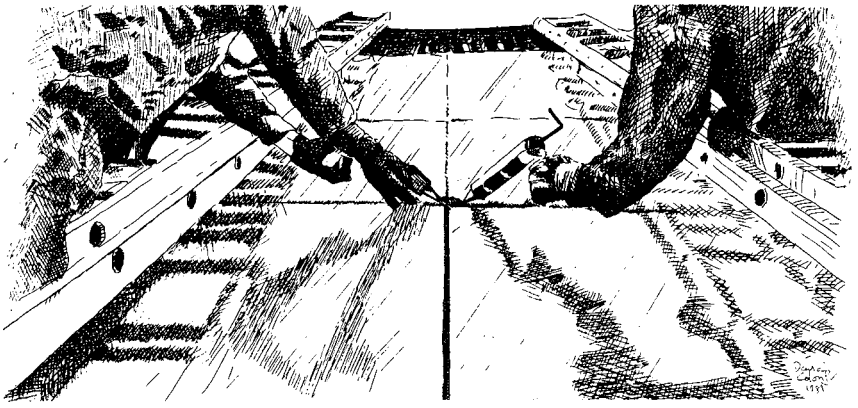
Solar collectors can be used to make a heat pump operate more efficiently, since the added heat from the collectors improves the heat transfer at the delivery end.

System Quality

Any new and growing industry has pitfalls for the buyer, including unscrupulous salesmen and incompetent installers. Even a reputable manufacturer produces an occasional "lemon," as everyone knows. Wise consumerism, an understanding of how solar systems work, and plain common sense are the buyer's best protection.

As with any other expensive investment, the buyer should shop around -- not just for the best buy, but for the best package. That package should include

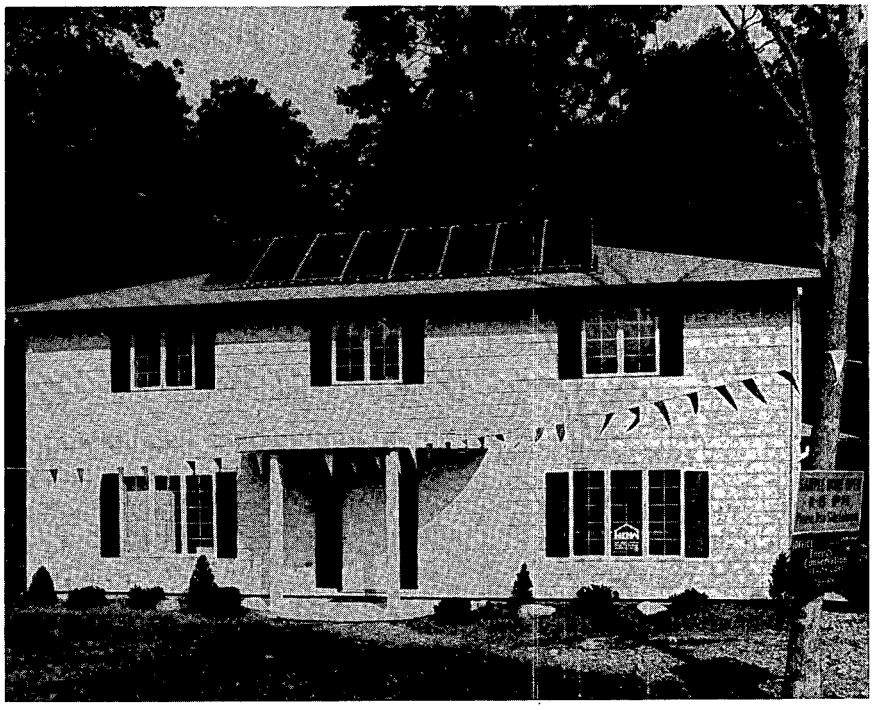
- a contractor with experience, a good reputation, and a record of satisfied customers in the area who can be contacted;
- a written estimate of costs, including parts, labor, permit fees, and service contract charges;
- a written estimate of system performance at the site;
- good-quality parts that will continue to be available over time;
- a system that has been performance-tested and meets the standards of ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers);
- written warranties for the system and the installation work, a service contract, and an owner's manual.



The Bottom Line

Depending on whether it is manufactured or homemade, dealer or owner-installed, partly or fully automated, the price of an active solar collector system will vary greatly. A domestic hot water system will cost between $2500 and $5000.

With space heating systems, which are larger, the costs are higher, ranging from $3000 to $15,000. Estimates are often made by square foot of collector, with $40-55 per square foot being average for an installed system including plumbing and storage.



Grumman Energy Systems, Inc.

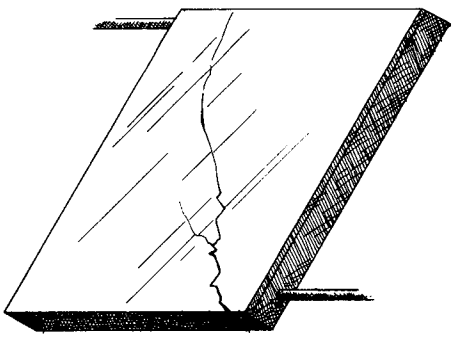
The payback period for an active solar heating system is linked to the kind and price of the conventional fuel being used previously. Depending on whether the owner uses oil, gas, electric heat, or wood, and depending on the local cost of the fuel, an active solar water heating system will pay for itself in four to ten years, and a space heating system will pay for itself in anywhere from five to twenty years.

The prices and paybacks described above are subject to a variety of changing factors. Inflation increases costs (both of fossil fuels and solar systems), but growth in solar manufacturing will tend to reduce solar costs. Well trained do-it-yourselfers may be able to build efficient, homemade systems or systems from kits or components for well under the going commercial rate, or save money by buying commercial systems but doing the installation themselves.

See Chapter 22 for information about tax incentives for the solar buyer.

System Safety

Whether manufactured or homemade, the solar collector system requires a certain amount of understanding for safe operation.



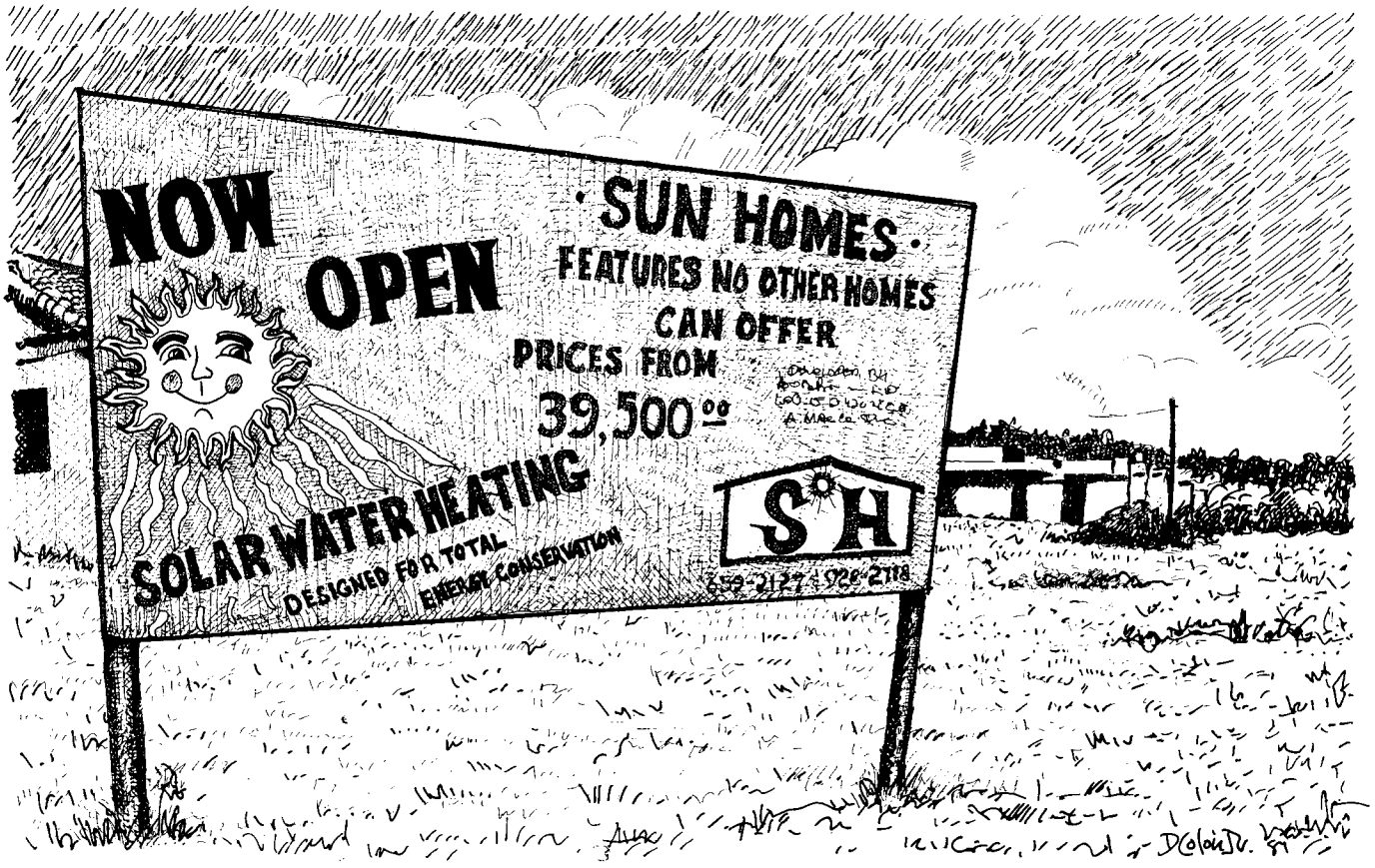
First of all, solar collectors can get extremely hot. Pipes and ducts leading from the collector should be well insulated, both for efficiency and safety. The collector container must be insulated and fireproofed to prevent possible melting, charring, or burning of the container or the surface it is mounted on.

Any time that the system is not operating, it will heat up in the sunshine because the transport fluid is not continually carrying heat out of the collector to storage. A "stagnant" absorber plate can soar to over 200°C (about 400°F). If the system suddenly goes on, the cool transport fluid entering the hot collector can then cause "thermal shock," breaking the glazing, cracking or warping the absorber, and bursting the pipes.

Stagnation, freezing, fluid expansion, pressure, and the generation of steam; any of these can cause system damage. The importance of proper installation can't be overstated.

If the transport fluid in the system is toxic, all pipes should be clearly marked to distinguish them from the pipes for potable water. A double thickness heat exchanger is recommended, and toxic transport fluids are usually colored so that a leak into the household water supply will be detectable. A backflow prevention valve will keep water supplied to the collectors from flowing back into the general water supply.

As a final safety consideration, solar collectors should be mounted where they are accessible for repair and service, but not for pranks and damage.



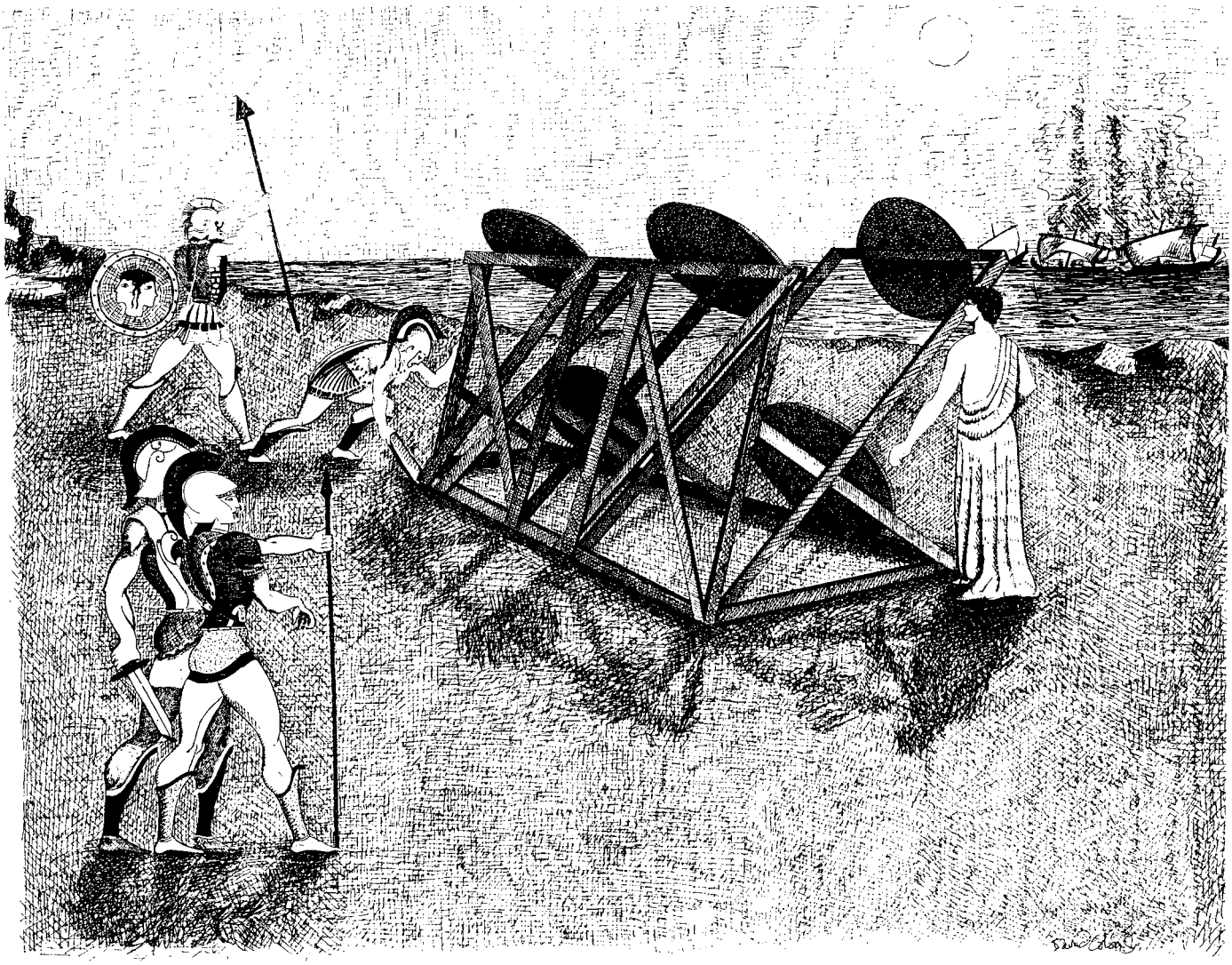
Making a Solar Investment

An active solar collector system is less complicated than many of the machines and appliances we use every day. And although the initial investment is a major one, the energy saving from a well-installed, efficient system is also major since the fuel itself is free. The active solar option is a real one for many families and businesses.

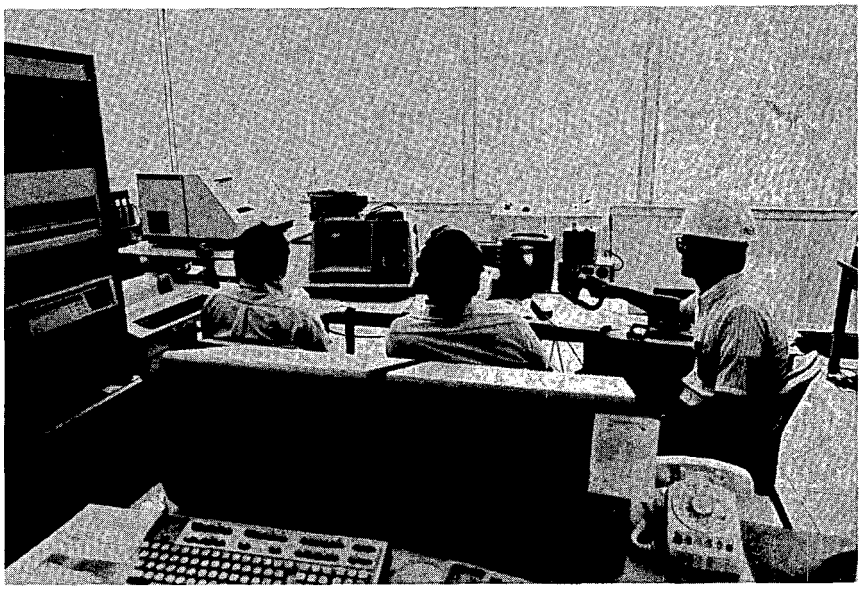
Chapter 16

Concentrated Sunshine

The ancients had a great regard for the sun as the major source of energy in their lives. They were fascinated by the problem of how to intensify sunlight to achieve high temperatures. Many early drawings show their efforts to envision how this could be done. "Burning glasses" were known in ancient China, Greece, and Rome, and by 200 B.C. the Greeks had arrived at the geometrical key to concentrating solar energy.



Today researchers and engineers are refining this ancient knowledge to use solar radiation to achieve the temperatures needed for modern industrial processes and the generation of electricity.



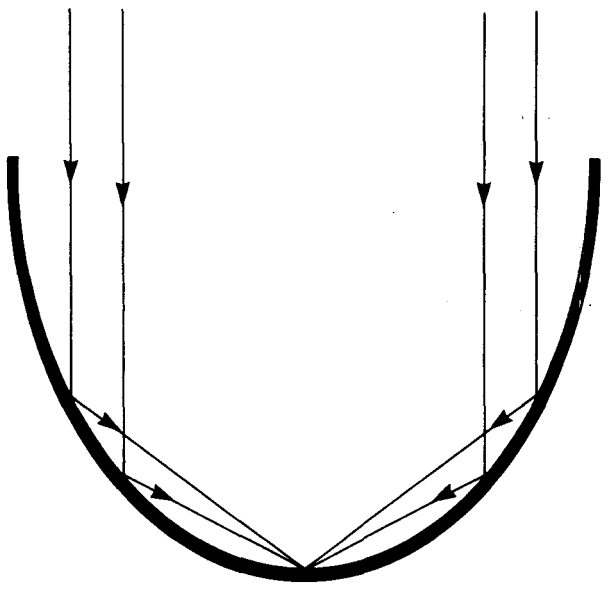
Georgia Institute of Technology

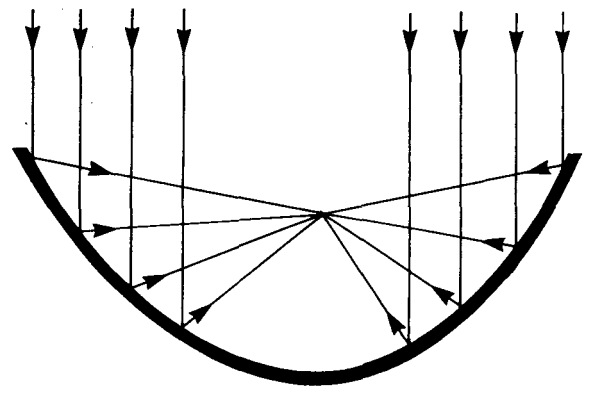
The Power of the Parabola

The key to concentrating sunlight is the parabola. The solar energy we receive on earth is not very intense: first, because of the distance it has traveled, and second, because of the depleting effects of the atmosphere. Still, there's a lot of it, spread over a large area. If a large, dispersed amount of insolation can be focussed on a small point, that point will receive a very large amount of radiation.

parabola: a curve formed by points equidistant from a fixed line and a fixed point not on the line.

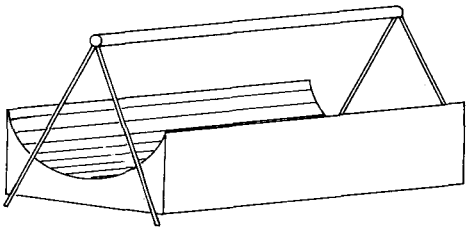
This is precisely what a reflector with a parabolic shape can do. The diagram below shows how various parabolic reflector shapes can be used to target points where radiation is to be focussed. Solar devices that take advantage of this principle are called concentrating collectors.





There are two main types of collectors for concentrating solar radiation: line focus collectors and point focus collectors.

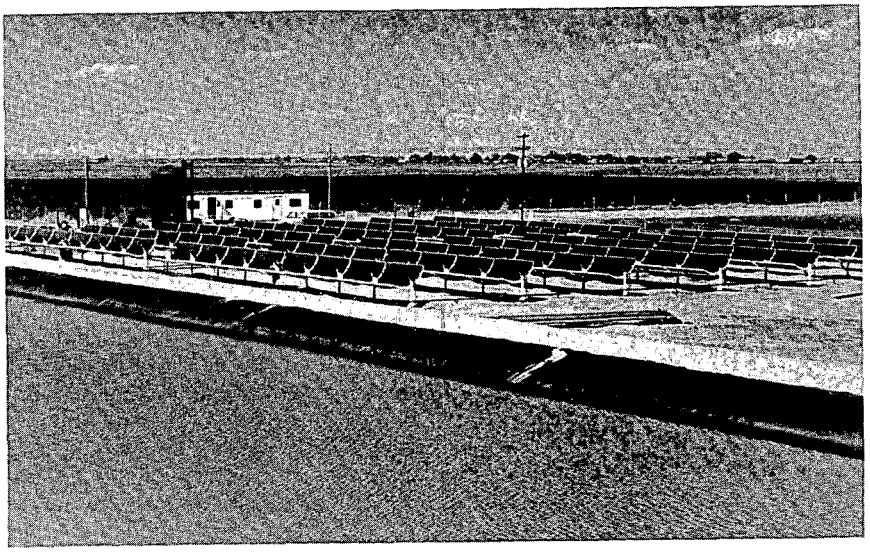
Line Focus Collectors



Parabolic trough

If you make a two-dimensional parabola of a reflective surface, the result is a sort of parabolic half-cylinder or trough. Sunlight striking this surface will be reflected to focus along a line running the length of the cylinder. Line focus collectors are designed with a pipe that carries a transport fluid along that line of focus. The concentration of radiation on that line can achieve temperatures from 100°C to 400°C. The problem then becomes how to transport and store the collected energy without major losses. Some collectors have a glass tube around the transport pipe and the reflector. The glass tube is evacuated (contains a vacuum) and this reduces heat losses.

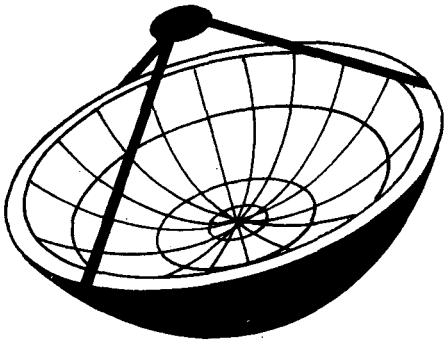
Line focus collectors are being used for space heating and air-conditioning, electrical generation, and production of steam for industrial processes. Large installations of many such collectors are called distributed collector systems.



Sandia National Laboratories

These parabolic trough collectors generate electricity to power two hundred thirty acres worth of irrigation in New Mexico.

Point Focus Collectors



Parabolic dish

Solar radiation can be concentrated even more intensely with a point focus collector. Instead of the parabolic trough, which beams radiation at a line, a parabolic dish is used, which beams all the radiation received toward a given point. Collectors using point focus achieve temperatures of over 400°C, and some large installations of this type have recorded temperatures of over 4000°C. (The temperature of the surface of the sun is about 5000°C.) With temperatures like these, electrical generation becomes more efficient and the melting of metals becomes feasible; point focus collectors are appropriately called "solar furnaces."

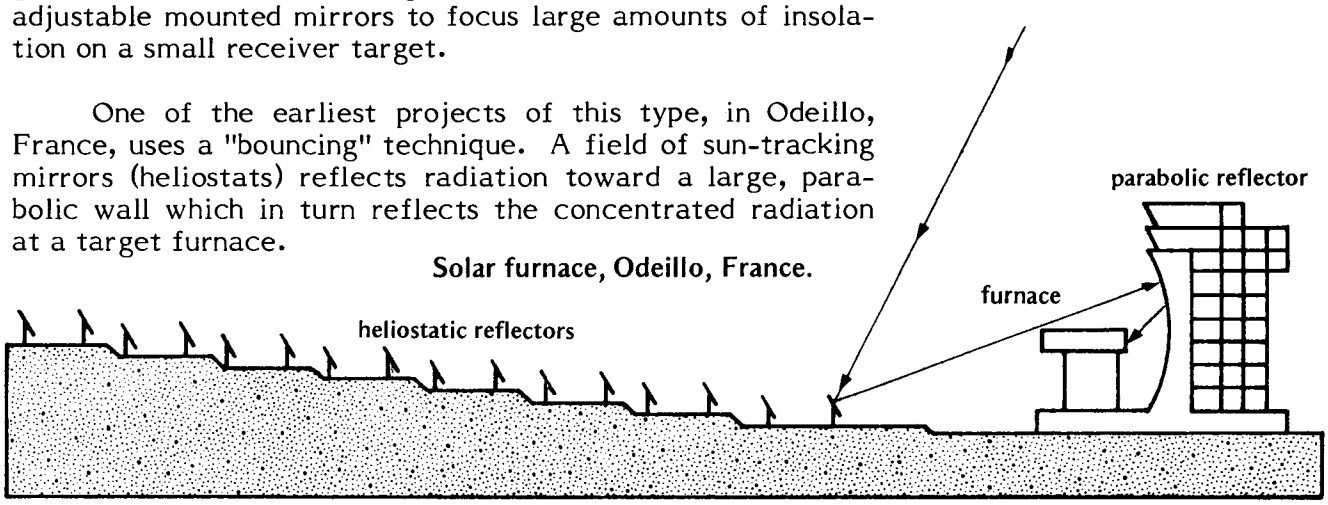
Power Towers

The largest-scale efforts to apply the principle of point focus are known as central receivers or power towers. These giant installations use large areas of land covered with adjustable mounted mirrors to focus large amounts of insolation on a small receiver target.

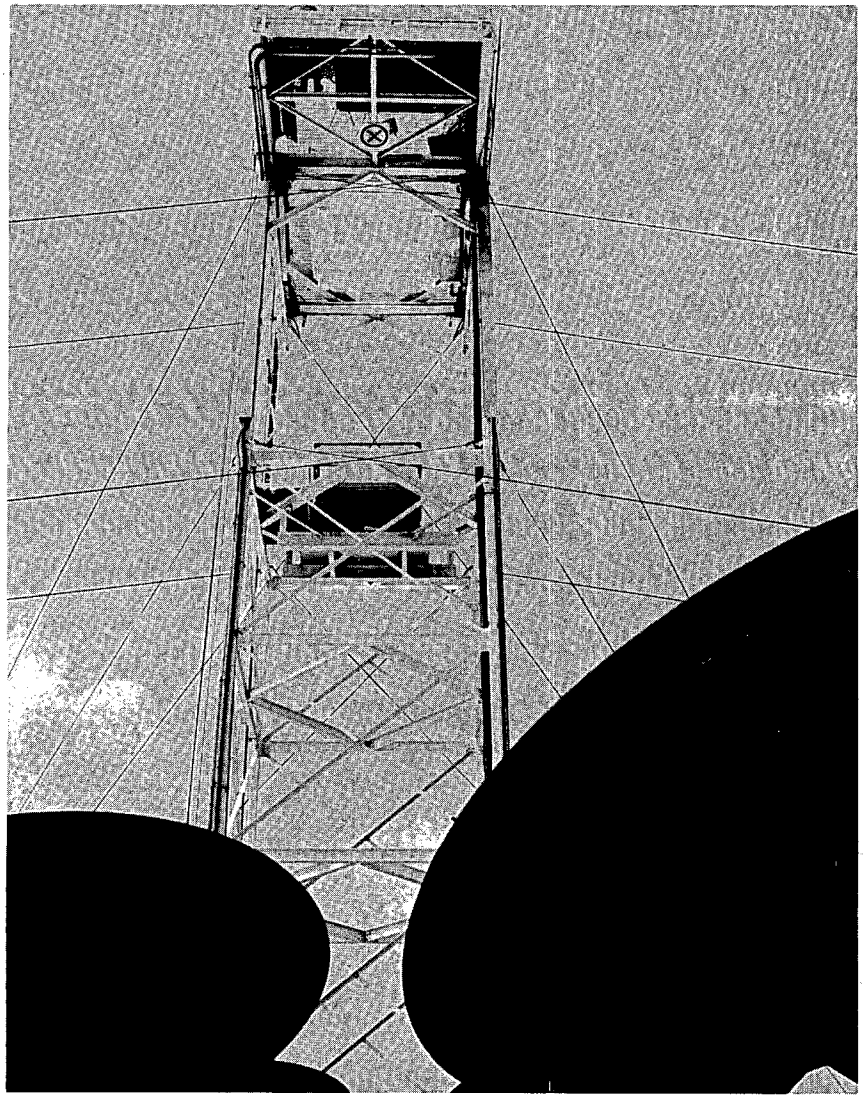
heliostat: a sun-tracking instrument. (See glossary.)

One of the earliest projects of this type, in Odeillo, France, uses a "bouncing" technique. A field of sun-tracking mirrors (heliostats) reflects radiation toward a large, parabolic wall which in turn reflects the concentrated radiation at a target furnace.

Solar furnace, Odeillo, France.



Other designs place the focal furnace at the top of a tower, surrounding it with sun-tracking reflectors, all focussed on the furnace. Each individual reflector is slightly



Georgia Institute of Technology

This central receiver in Georgia is designed to test experimental solar thermal hardware. The center of the focal zone achieves temperatures approaching 1900°C (3450°F).

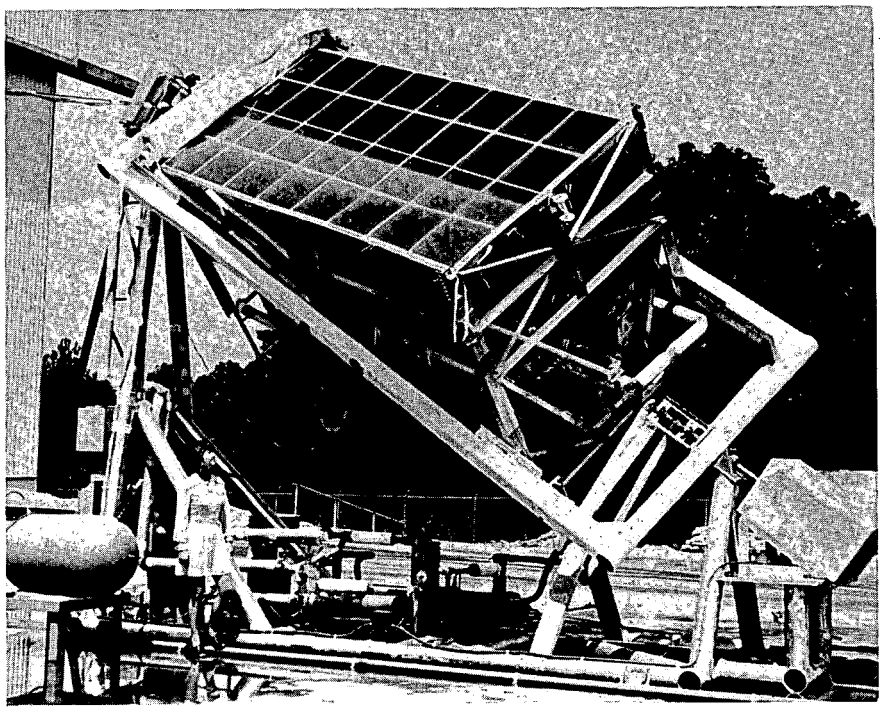
curved and all the reflectors together, when properly adjusted, form one huge parabola.

The Use of Lenses for Point Focussing

Fresnel lens: a thin lens that acts as a thick lens, due to its serrated sections.

Another way of focussing radiation on a point is to use a lens. The production of large, accurate lenses is difficult and costly, however, and large lenses are heavy, so they are not getting much attention in solar research. The exception is the many-faceted Fresnel lens, which can be manufactured cheaply of plastic and gives good concentration efficiencies. A special application of the Fresnel lens will be discussed in the chapter on photovoltaics.

One advantage of lenses is that they also serve as windows, protecting the absorber and reducing heat loss.



National Aeronautics and Space Administration

The "windows" of this experimental collector are Fresnel lenses, which concentrate the radiation that passes through them.

Problems with Concentrator Collectors

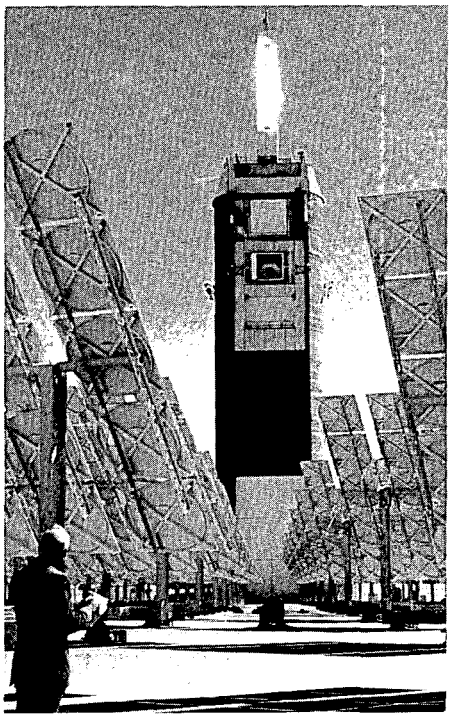
The concentration of solar energy to achieve high temperatures poses challenging engineering problems. The question is not whether it can be done, but how to do it efficiently and cost effectively.

One problem is to select materials that will do the job without deterioration from weather, radiation, or constant exposure to high temperatures. The higher the temperatures achieved, the more difficult this problem becomes.

Perhaps the most expensive part of the design is the tracking mechanism for the reflector or concentrator. Since the earth rotates, the concentrator must rotate in the

opposite direction to compensate. Sun-tracking mechanisms, called heliostats, operate continuously through the day, following the sun and keeping the target in focus.

Finally, the solar concentrator faces the same problem as the passive home or the flat plate collector: sunlight is intermittent. Storage or a backup energy source are therefore necessary for any practical design. In the case of a large-scale facility, the utility power grid could be the "storage," using solar electricity when it is available and other fuels when it is not.



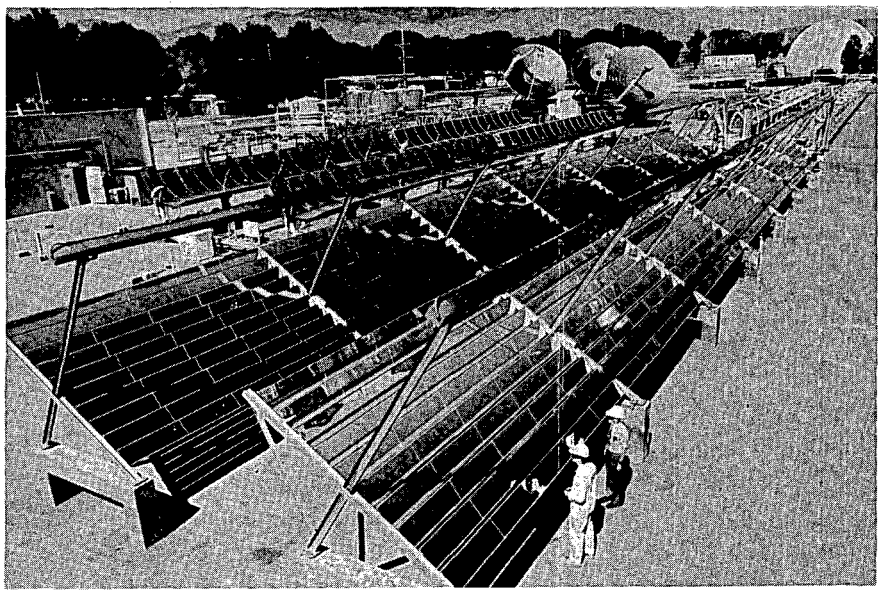
Sandia National Laboratories

The D.O.E. Central Receiver Test Facility in New Mexico has 222 heliostat arrays, each containing 25 four foot square mirrors.

The Long View

So far the practicality of concentrating collectors has depended on their expense, scale, and the temperatures needed. While the power tower remains primarily a research endeavor, line focus collectors in distributed systems are already finding some acceptance. The temperatures they achieve, although lower than those achieved by point focus collectors, are sufficient for space heating and cooling, industrial processes, and localized electrical needs.

Concentrating collectors, though expensive, offer a relatively safe, clean, and renewable source of high temperature heat for utility and industrial use. Whether these technologies will soon find wider acceptance will depend on people's concern about energy supply and the environmental impacts of energy use. Whatever the present outcome, we can be fairly sure that, as in ancient times, people will continue to be interested in how to concentrate sunshine.

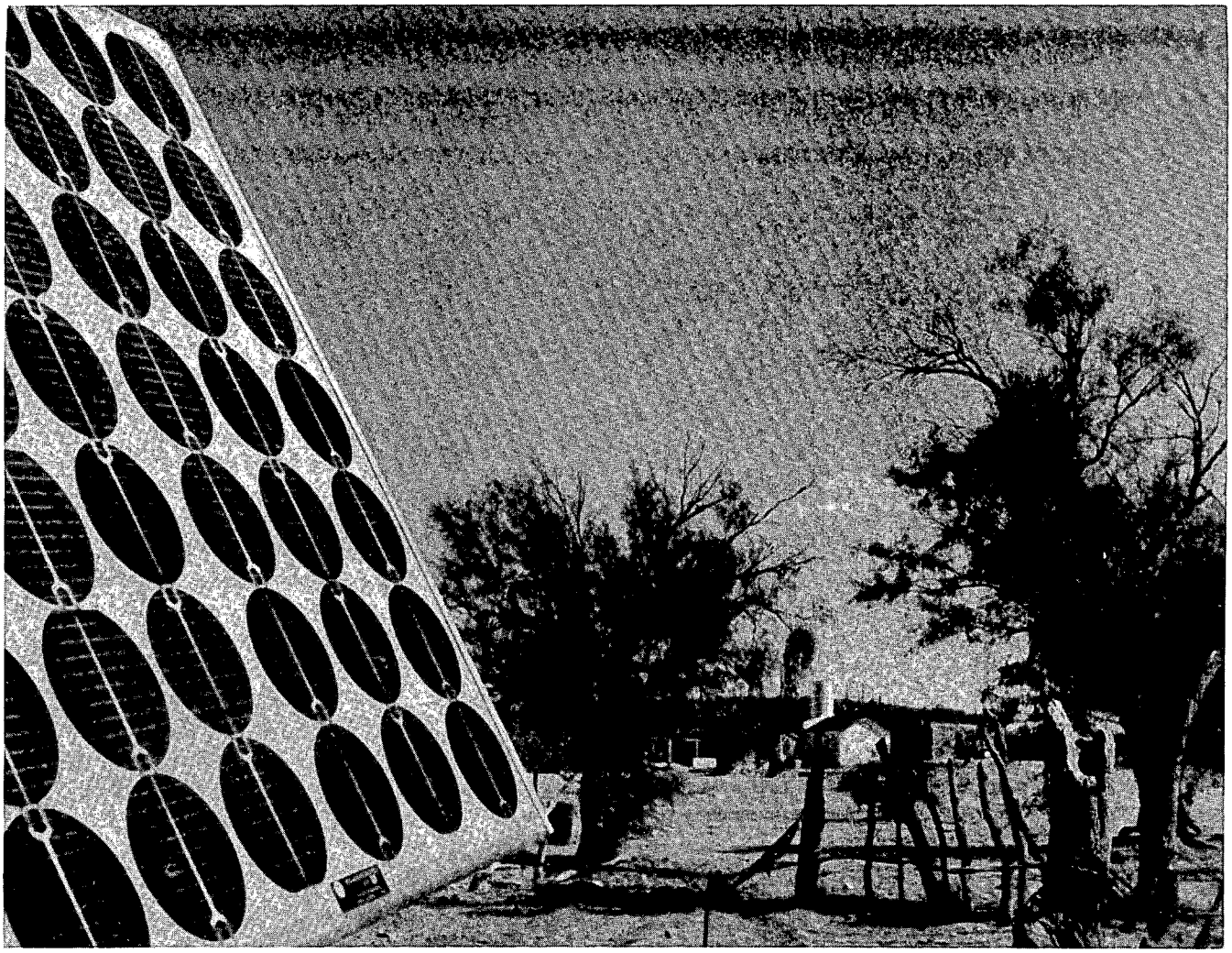


Sandia National Laboratories

Chapter 17

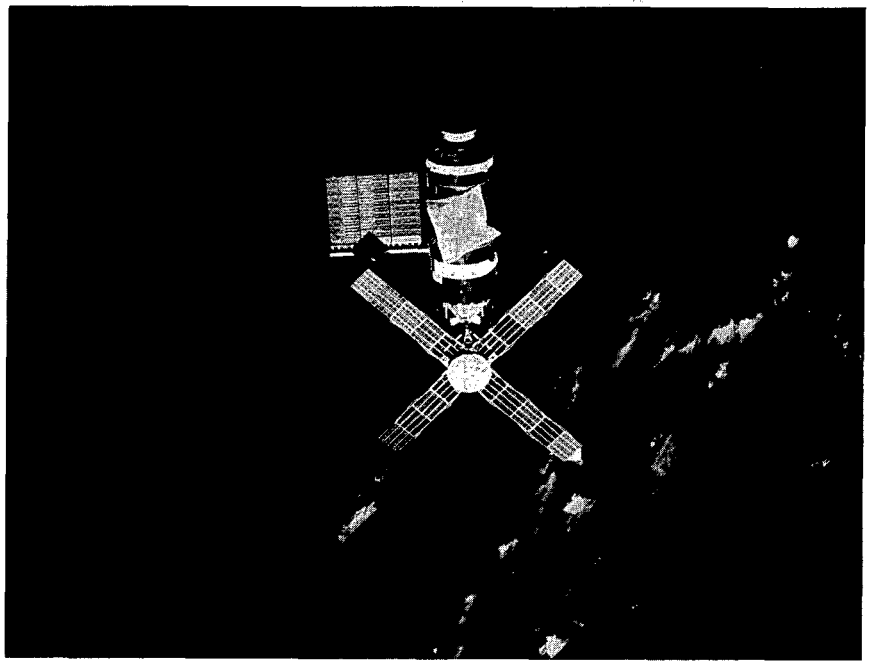
Volts from the Sun

Studying about photovoltaics can be a very frustrating experience because the "state of the art" changes virtually overnight. In 1977, general opinion was that photovoltaics might be commercially competitive by the year 2000. In 1979, experts shaved ten years from that estimate. Today, commercial photovoltaics seems to be virtually on the horizon.



National Aeronautics and Space Administration

Twenty years ago solar cells were familiar only as the power in photographic light meters. The solar cells on satellites during the space program of the 1960's raised public consciousness, but well into the 1970's they were considered expensive, exotic, and only suitable for remote locations where normal electric transmission was impossible.



National Aeronautics and Space Administration

Arrays of solar cells powered Skylab.

Now homes with photovoltaic roof arrays have been built and are being lived in. As the technology of solar cells advances and the availability of conventional fuels drops, photovoltaics, like other solar technologies, looks less fantastic and more practical every day.

What is this exciting technology and how does it work?

The Nature of the Solar Cell

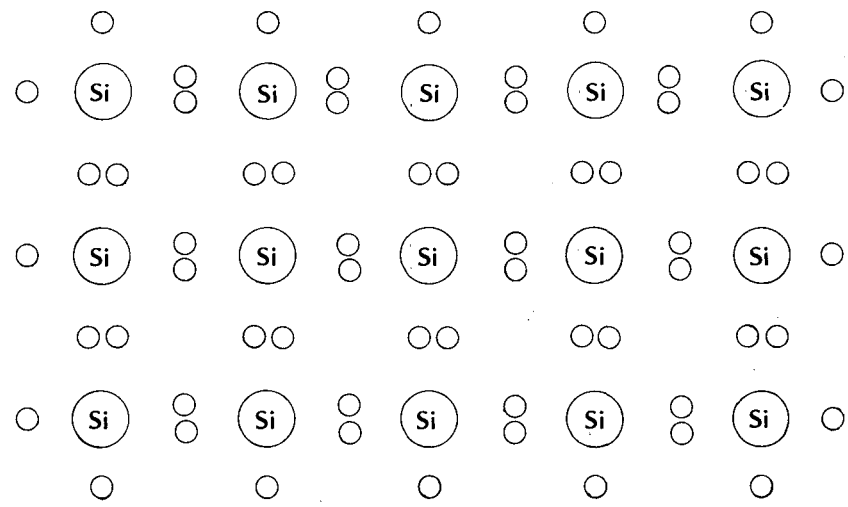
The word "photovoltaics" means light-generated electricity. The phenomenon by which light is converted directly to electricity is called the photovoltaic effect, and the devices that do the converting are called photovoltaic cells or solar cells. A collection of these cells, mounted, is called a photovoltaic module. A collection of modules is called an array.

The materials used are semiconductors, compounds and elements which have some unusual and interesting properties. The element most widely used in solar cells is silicon, so we will use silicon in explaining how a cell works.

semiconductor: a crystalline substance with medium conductivity.

Silicon and Covalent Bonding

The silicon atom has four electrons in its outer (valence) shell, and each of these tends to form a pair with an electron from another silicon atom. This pairing, called "covalent bonding" attaches the original silicon atom to four other silicon atoms in a stable relationship.

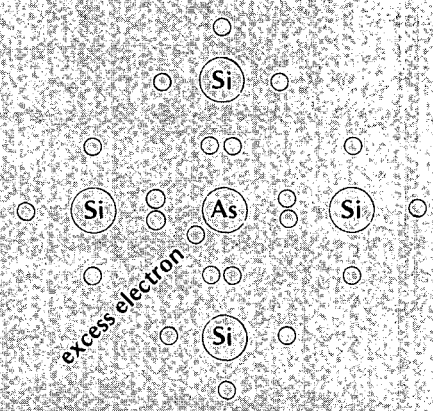


The four other atoms form similar bonds with other silicon atoms and a crystal lattice is formed.

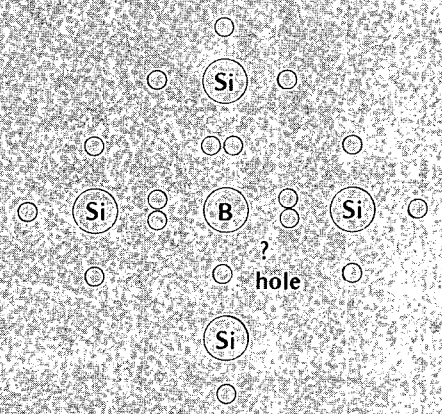
To get silicon, solar cell manufacturers take sand (silicon dioxide), and remove and purify the silicon. To give the solar cell its special properties the pure silicon is then "doped" with minute amounts of other elements that also join in the covalent bonding of the crystal lattice. This doping process converts the element to a semiconductor. One part per million of the doping agent is enough to do the job.

N-Type and P-Type Silicon

Arsenic, phosphorus, and antimony all have five valence electrons and are used to dope silicon. If a small amount of one of these (let's say arsenic) is added to silicon, there will be an excess of electrons that can't share in covalent bonding. (Remember, these are not excess electrons in the electrical sense; they don't give the silicon a negative charge. They are only "excess" in terms of covalent bonding.) These excess electrons can move rather freely. Silicon that has excess electrons due to these added impurities is called N-type silicon. It is still electrically neutral, but it has electrons that are rather loosely attached to its structure.



Suppose, on the other hand, that we add small amounts of boron, gallium or indium, which have only three valence electrons, to pure silicon. Instead of having an extra electron, the covalent bonds are one electron short. There is a "hole" in the lattice and we call silicon with these free holes P-type silicon. Again, it is electrically neutral, but has a tendency to bond with loose electrons.



In effect, the N-type silicon will act as if it is negatively charged and the P-type silicon will act as if it is positively charged.

Bringing the Two Together

A solar cell consists of a layer of N-type silicon with a transparently thin layer of P-type silicon spread over it (or vice versa). What happens when the two are sandwiched in this way?

The surface where the two types of silicon meet is called the P-N junction. At this junction the loose electrons of the N-layer combine with the holes in the P-layer to form a stable bond.

But now there is a charge on either side of the junction. The N-layer has given up loose electrons and thus acquired a positive charge. The P-layer has filled the holes in its covalent bonds with loose electrons from the N-layer, and has become negatively charged.

Creating Current in a Solar Cell

At the P-N junction, then, we have stable covalent bonds between the two types of silicon, with opposing charges on either side. The opposing charges create a barrier so that other loose electrons from the N-layer cannot cross to fill other holes in the P-layer.

The surface of the solar cell is now exposed to sunlight. Photons (the little bundles of energy that make up light) collide with valence electrons of the atoms of silicon at the P-N junction. If the photons have just the right amount of energy, they knock valence electrons loose, creating more holes.

As the electron-hole pairs are created by the photons striking the electrons at the junction, the electrons and the holes move under the influence of the opposing charges at the P-N junction in opposite directions. The free electrons are drawn by the net positive charge of the N-layer; the holes are drawn by the net negative charge of the P-layer.

Suppose we have attached electrodes (wires) to the top and bottom of the cell. Recombination of holes and electrons occurs throughout both regions of the crystal in a "bumping" pattern, starting at the P-N junction and ending at the two cell surfaces. However, the "bumping" or displacement of free charges (electrons) toward the lower surface and of holes toward the upper surface establishes a potential difference (voltage) between the two surfaces. Electrons the will travel from the bottom electrode (N-layer) through the wire to the top electrode and P-layer where they combine with holes. If we connect the two electrodes to an external load (a transistor radio, for example), the current of electrons will power the radio as they travel through.

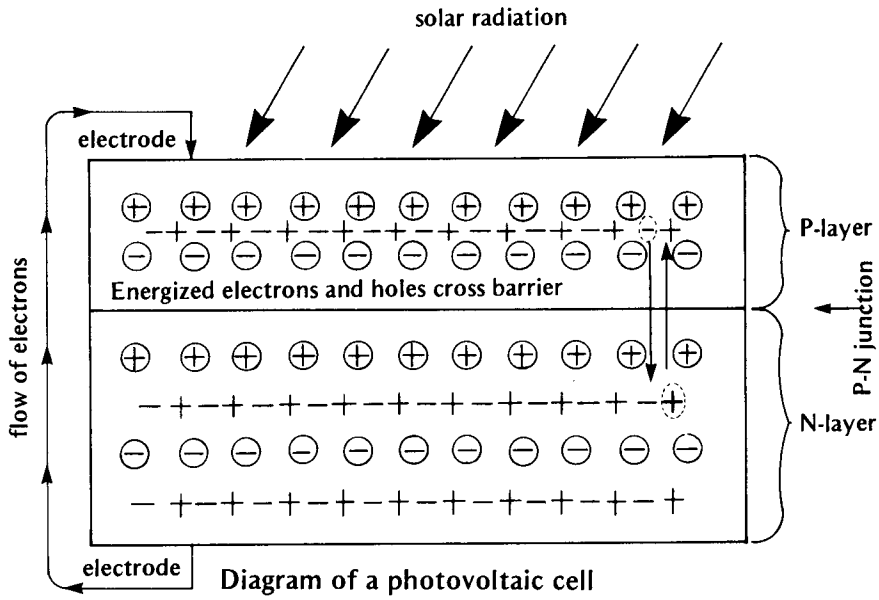
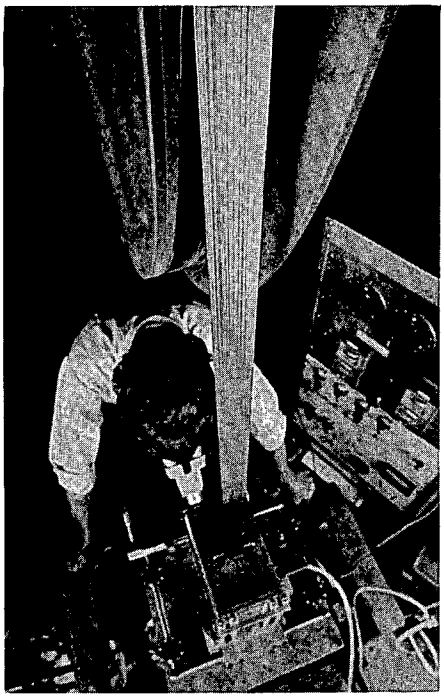


Diagram of a photovoltaic cell

Briefly stated, photovoltaic electricity is generated when sunlight strikes a cell consisting of two different semiconductor layers. The layers are arranged so that when sunlight strikes the cell and knocks electrons loose, the electrons will tend to move in one direction, creating a current in attached wires.


Mobil Tyco

Growing silicon ribbon eliminates the wasteful process of having to slice solid silicon ingots.

amorphous film: a thin film of semiconductor which is not entirely crystalline.

Problems and Breakthroughs

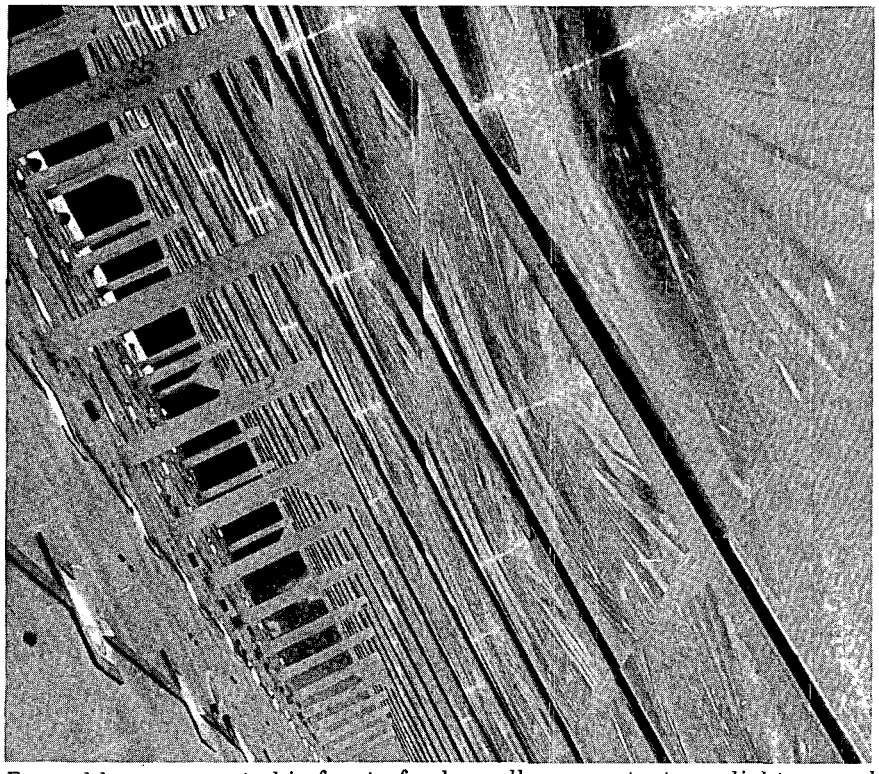
The problem of the photovoltaics industry is this: to make a cheap, durable, and efficient cell.

Though the raw material, sand, is cheap, pure single-crystal silicon is expensive to produce. Growing the crystals is a slow process, and slicing them into fine layers is a delicate job and wastes as much as half of the silicon. The round crystal slice wastes space in a module. Oxidation around the electrode causes corrosion. Efficiencies for cells are low, requiring very large arrays to produce sufficient power.

These problems have been attacked by inventors and industry from many angles, in a headlong race to produce the cheapest, most efficient cells and modules.

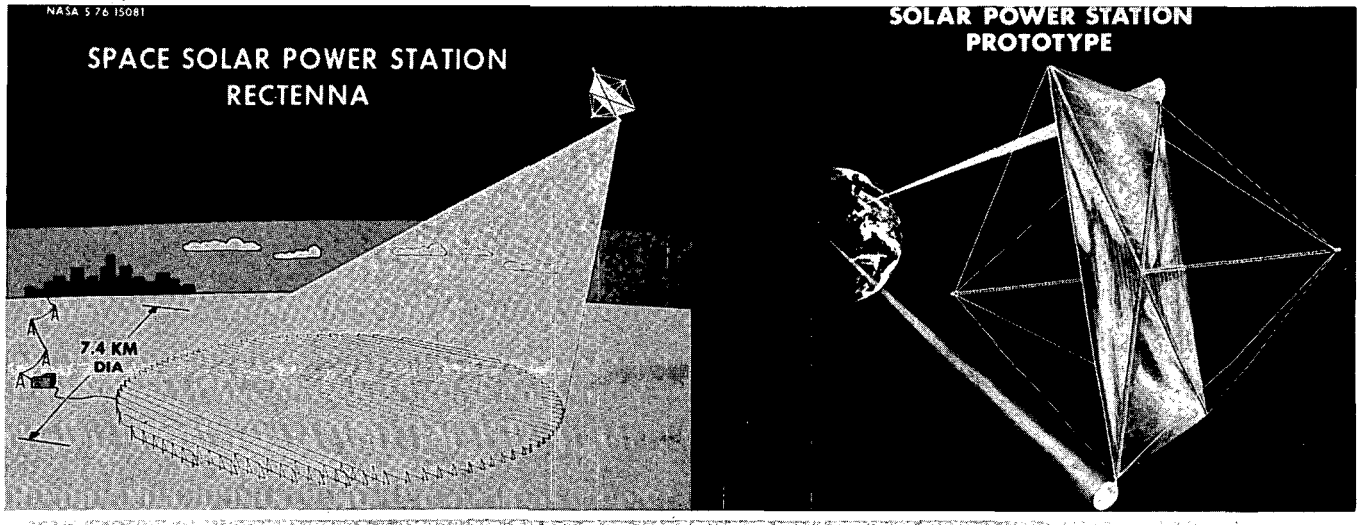
Some industries, in addition to single-crystal silicon, are also experimenting with cheaper polycrystalline silicon and amorphous silicon films which can be deposited on an underlying surface. Others are working with casting rectangular ingots or growing the crystal as a ribbon, so that cells can be made square instead of round for better space economy and to avoid the wasteful slicing process.

To reduce the number of cells needed, while improving efficiencies, some cell designers are combining concentrating reflectors or Fresnel lenses with cell arrays.



Sandia National Laboratories

Fresnel lenses mounted in front of solar cells concentrate sunlight on each cell, increasing electrical output per cell.



The Solar Power Satellite

The most ambitious plan for using solar cells is the idea of the solar power satellite (SPS). Many square miles of cell arrays, assembled and orbiting in space, would transform sunlight to electricity which would then be converted to microwaves. The microwaves would be transmitted to a receiving station (rectenna) on earth.

Supporters of the SPS concept point out that the more intense, 24-hour-a-day sunlight of space would make optimal use of solar cells. One satellite could produce as much as five billion watts of electricity.

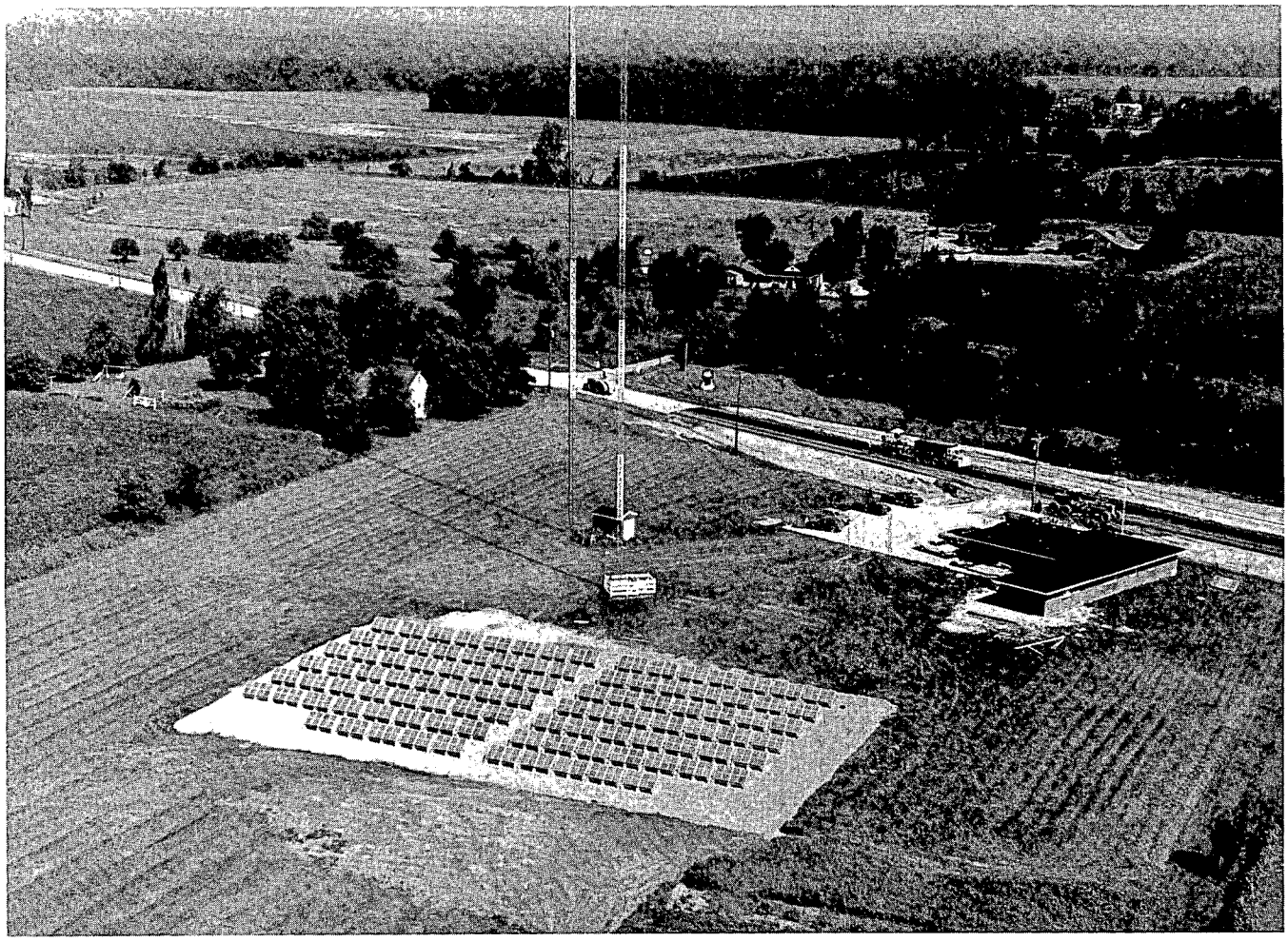
The plan's detractors argue that little is known of the environmental and health effects of large-scale microwave transmission, and that the rectannas would consume large areas of land. Some people also feel that the enormous price tag of the project (about one trillion dollars for a fleet of 60 satellites) would be better invested in more down-to-earth efforts.

The Last Lap

With so much dedicated and competitive effort, the question with photovoltaics has changed from "if" to "when." One unresolved problem (typical of all solar technologies) remains: the problem of storage. Storage batteries are a possible, but expensive, solution. The best answer may lie with local utilities. If the owner of the photovoltaic home or business could feed excess electricity into the power grid during peak sunlight hours, and draw upon the utility for power at night, both utilities and private owners would benefit. In fact, neighborhood and local cooperatives and utility companies may become the largest market for photovoltaic cells, using cell arrays to substitute for conventional generating fuels whenever possible.

power grid: the electricity supply network for an area.

If the pace of photovoltaic growth today is any indication, we won't have to wait for the year 2000 to see solar electricity become an accepted part of everyday life.



Lincoln Laboratory, Massachusetts Institute of Technology

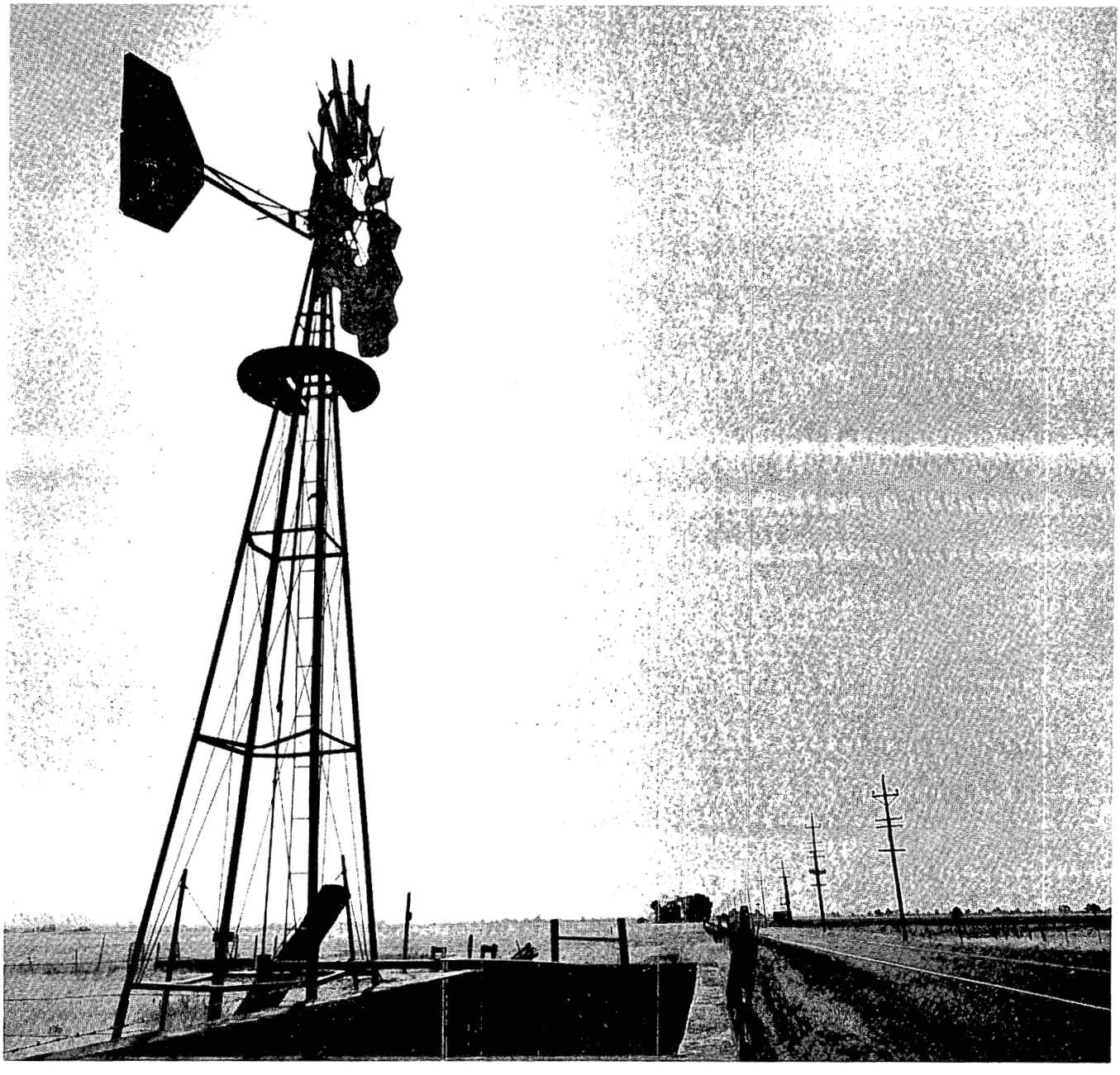
Photovoltaic cells power this Ohio radio station.

Chapter 18

Wind Power

If we imagine the earth as a machine, then solar energy is the fuel that drives it. But that energy undergoes many transformations in driving the earth's complex machinery. One of these transformations is the convective cycle of heated air which creates wind, a cycle that was discussed in detail in Chapter 7.

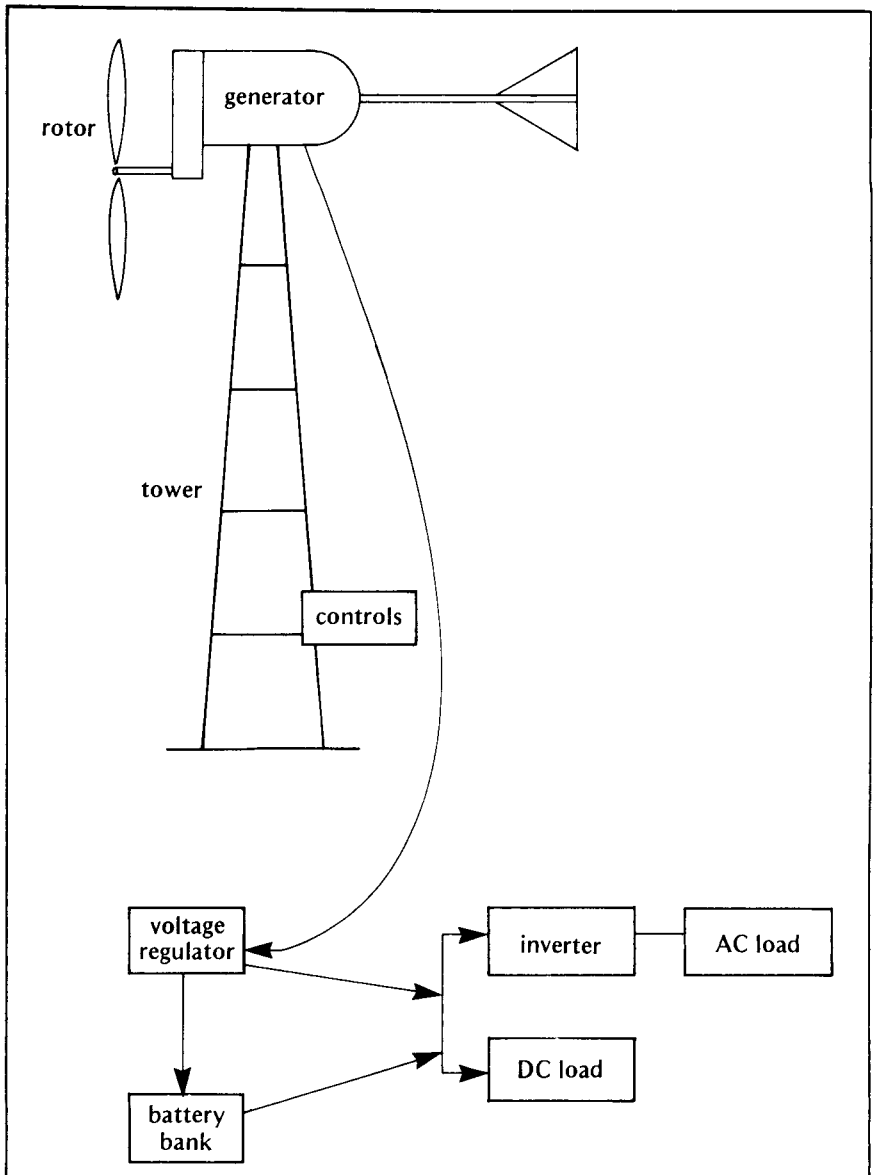
The transformation from radiant to thermal to kinetic wind energy is useful because it provides energy in a form that can be tapped with a different technology, one that has been with us for centuries. Wind machines changed the face of Europe, helped open the American West, and brought water to the surface of many a dry wasteland. In fact, some places that have the poorest supplies of direct solar radiation are rich in this secondary form of solar energy.



Pacific Gas and Electric

Wind Machines

Devices that draw kinetic energy from the wind have been with us for hundreds of years. Early windmills were used to pump water or turn mill wheels, and these functions are still important in developing regions. Many of today's machines produce electricity, and are more properly called wind-powered generators. Both windmills and wind-powered generators are referred to by the general name of "wind energy conversion systems" (WECS). The basic parts remain the same: sails or blades (the rotor), driven by the wind, turn an axis and its attached shaft. This revolving shaft may be geared to drive machinery, or may act as the spinning core in an electric generator. The machine is usually mounted on a tower, with speed controls and a brake to allow for dismantling or repairs. To store energy for calm periods, the machine may pump water into a raised tank, or charge storage batteries.

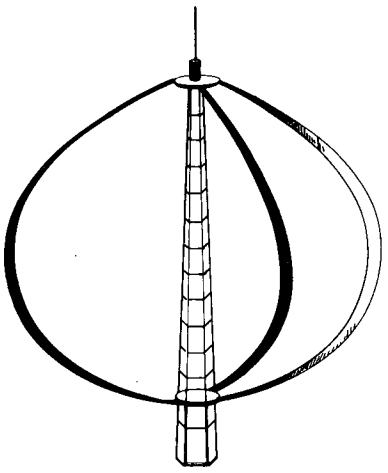


A wind energy conversion system

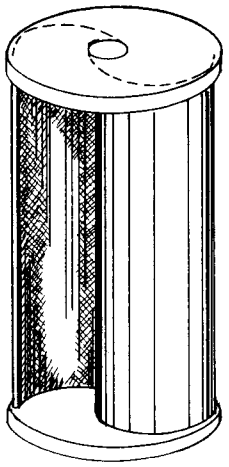
New Designs

Aerospace research into airfoils, aerodynamics, and new alloys and plastics has provided the wind industry with many new designs and materials. But some of the most futuristic designs predate the aerospace industry. Two of these, the Darrieus and the Savonius wind generator designs, mount the axis and shaft vertically, producing a look many people find bizarre and unfamiliar. Yet these vertical axis designs are fifty years old, and vertical axis wind machines were used in Persia a thousand years ago. The advantage of these machines is that they can catch wind coming from any direction.

aerodynamics: the study of the forces exerted by air and other gases on wind-blown objects.

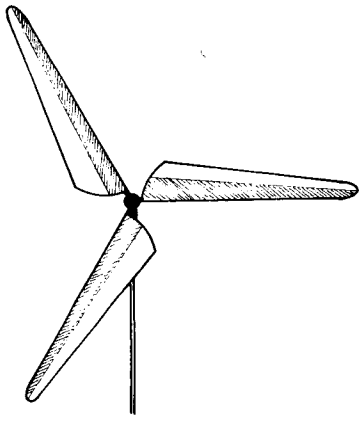


Darrieus rotor

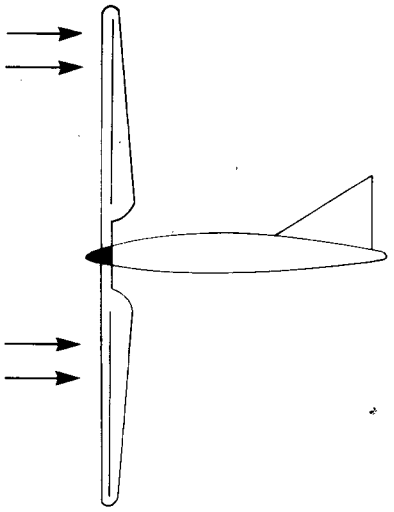


Savonius rotor

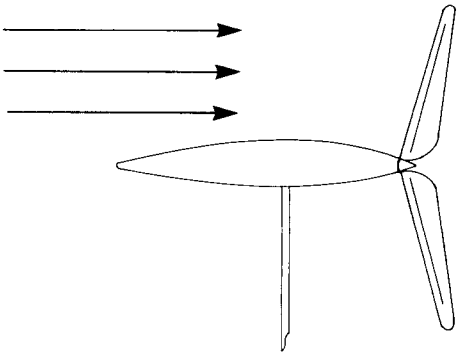
Most of the machines for sale today are horizontal axis machines, but the familiar many-bladed look of the 1800's is often replaced by one-, two-, or three-bladed designs with the appearance of airplane propellers. Unlike a vertical axis machine, a horizontal axis machine has to reorient itself as the wind shifts. Some have tail vanes to keep them facing into the wind; others are designed to operate facing away from the wind, with the blades slanted to act as the tail vane themselves.



Three-bladed rotor

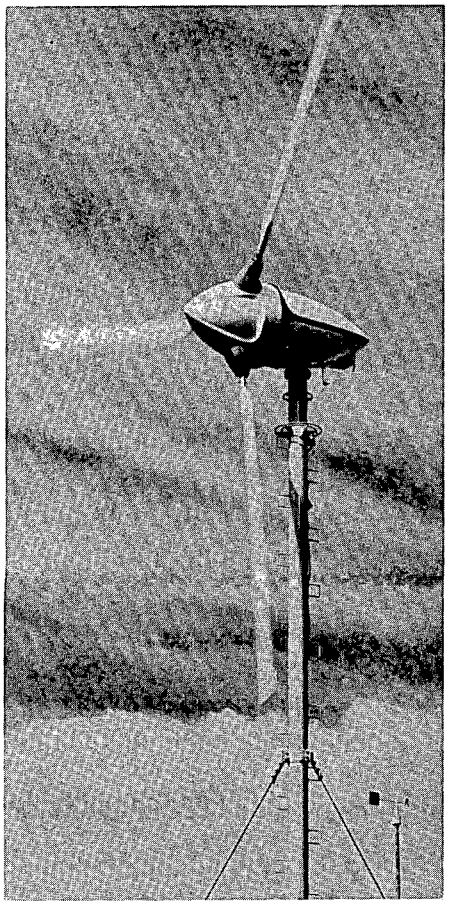


A tail vane keeps the rotor facing into the wind



A rotor designed to operate downwind

Whether to Choose the Wind



Windworks, Inc.

Wind machines are perhaps, to the general public, the most familiar of all the solar technologies. They were important in rural life, especially in the development of the Great Plains, from 1850 to 1950. Cheap fossil fuels and rural electrification brought that wind era to a close, but we are already seeing a resurgence of this practical technology. Familiar and practical though they may be, however, wind machines are neither simple nor cheap. The decision to invest in one demands an assessment of energy needs, machine efficiency and reliability, available wind, and costs.

Household Energy Demands

A home that makes heavy use of many appliances is unlikely to be able to meet all of its electrical needs with wind power. Even if the family could afford a large enough machine, the number of storage batteries needed to supply power in calm periods would be unreasonable. This is why many of the earliest adopters of wind power today have been people building homes in remote areas who found that the cost of having power lines brought to their site was prohibitive. These people are often willing to schedule their appliance use to accommodate the power supply of a wind machine.

For people who are already linked to the utility power grid, however, there are other possibilities. The grid, in effect, becomes the "storage battery," providing extra power when the house needs more than the wind system can supply. Wind power then becomes a question of percentages. How much of my electricity can the wind supply? How much will

The Synchronous Inverter

For the owner of a power generating system, whether wind, hydropower, or photovoltaic, the synchronous inverter has been an important breakthrough.

When the wind doesn't blow or the sun doesn't shine, the owner may need power from the utility company. But that power comes as alternating current, while power from the home supply is direct current. Most standard appliances also require alternating current. Another difficulty may be variations in voltage and frequency of the home power supply.

The synchronous inverter is one device for dealing with these problems. It takes direct current from the home supply and converts it to alternating current at standard line voltages and frequencies. It feeds power from the home supply to the load appliances, and when home power is insufficient it also draws from utility power. When home power exceeds the demand of the load, the synchronous inverter feeds excess power to the utility for use by other consumers. Recent legislation requires the utilities to buy home-generated power, and the synchronous inverter is one tool that makes the exchange possible.

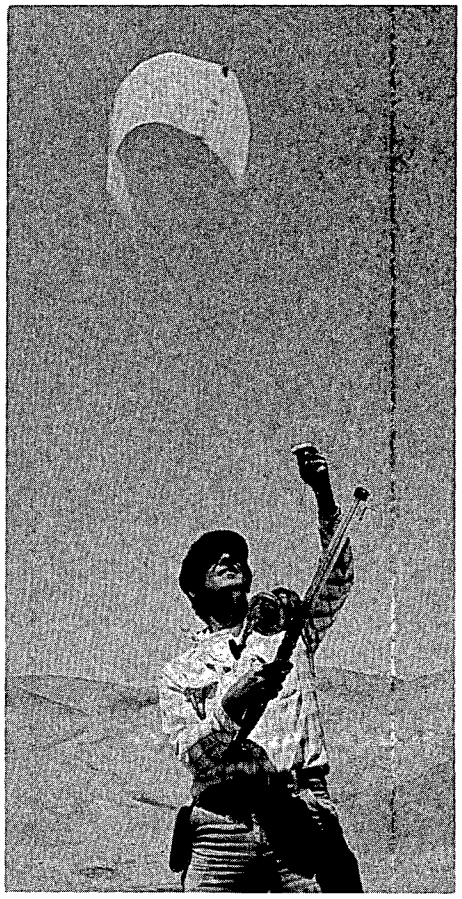
that save me? Can I sell excess power to the utility company? How long will it take to pay off the wind machine investment?

To answer these questions, one finds out first how many kilowatt-hours the house uses in a year, and then calculates a monthly or daily average. The next point to determine is your site's annual average wind speed at the proposed height of your tower.

Available Wind

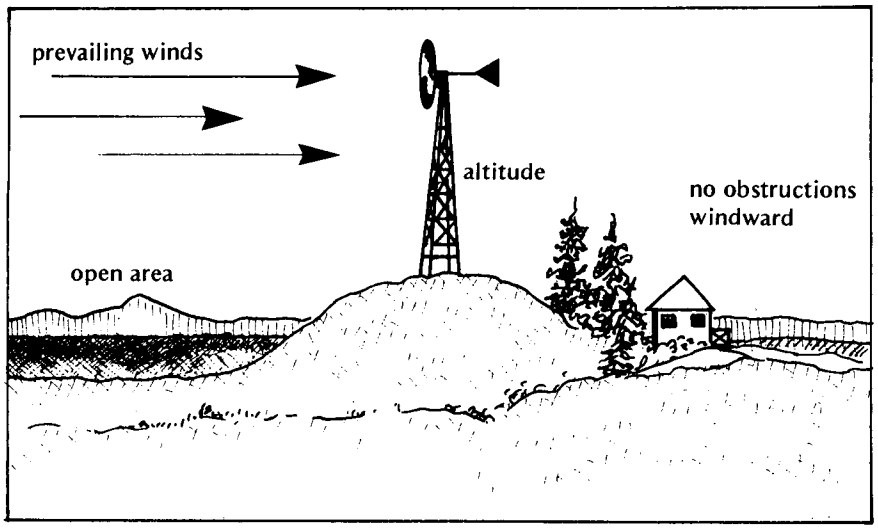
There are large variations in available wind, even within a fairly small area. Many features of the landscape like trees, fences, hills, and houses act as baffles, creating turbulence and extracting energy from the wind. Altitude, on the other hand, increases wind speed, and so do open areas such as large bodies of water.

Because of these site-specific features, it is not enough to use weather data from a weather station ten miles away to find out about your site. Many wind machines won't produce any current at all at speeds under 8 mph, and experts recommend an annual average wind speed of 12 mph or better to justify the investment. It's important, then, to be sure that your particular site has enough wind. Also, since winds vary greatly in speed and direction from season to season, a full year of monitoring is recommended to get an average.



Pacific Gas and Electric

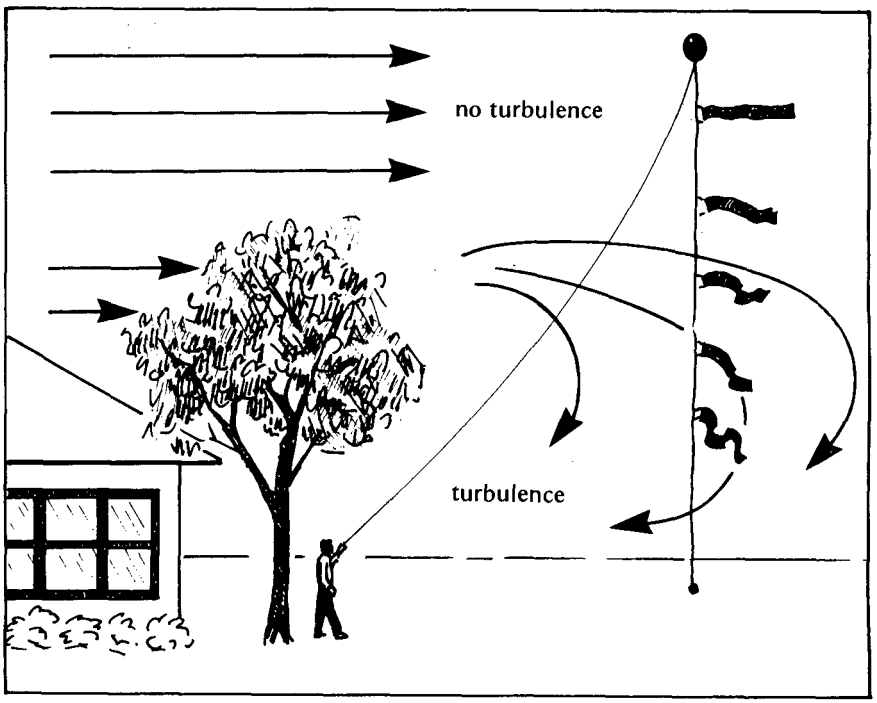
This sophisticated kite helps a utility company to measure wind at possible electric generation sites.



Characteristics of a good wind site

The height of the tower will be an important factor, since wind speed increases with altitude, and a tall tower raises the machine above the turbulence induced by the

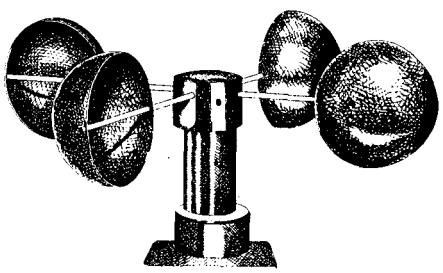
surrounding trees and structures. A kite or helium balloon carrying a weighted string with streamers placed at intervals along the string will help to show how high the tower must be to escape turbulence.



A "balloon test" shows where turbulence stops.

Once the tower height is estimated, wind speed at that height can be measured. A wind odometer, an anemometer with an odometer attached, may be bought or rented from a wind consultant or wind equipment distributor. This device measures the mileage of the wind over a period of time.

anemometer: an instrument which measures the speed of the wind.



Wind speed can be measured by mounting the odometer on a pole the height of the proposed tower. Alternatively, you can measure the wind speed at ground level and use the formula

$$\frac{V}{V_0} = \left(\frac{H}{H_0}\right)^n$$

to determine wind velocity at the height of the tower.

(V_0 is the velocity at the reference height H_0. For the normal range of wind speeds, n is 0.2.)

Since most people may not be able to do a full year's monitoring themselves, an alternative method is to "spot check" wind speeds at your own site and then compare them to those at the nearest airport or weather station. Such a comparison should enable you to use their annual average wind speed to estimate your own.

If you're not sure where weather data are collected in your area, contact the National Climatic Center's NOAA Environmental Data and Information Service, Federal Building, Asheville, North Carolina 28801.

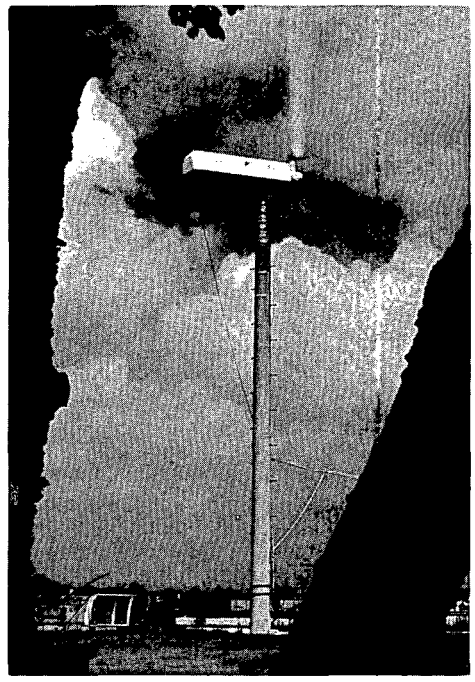
Machine Efficiency

After determining the household's electricity demand, and the average wind speed available, the prospective buyer has to determine how much energy a machine in his price range can supply. Every machine on the market has a "rated wind power" at a "rated wind speed." This tells you the power in kilowatts produced by the machine under optimal conditions. For example, a given machine may be rated to produce 20 kilowatts at a wind speed of 29 miles per hour (12.9 meters per second).

Don't be misled, however. These are optimal conditions, not average conditions. The power produced by a wind machine is proportional to the cube of its operating velocity.

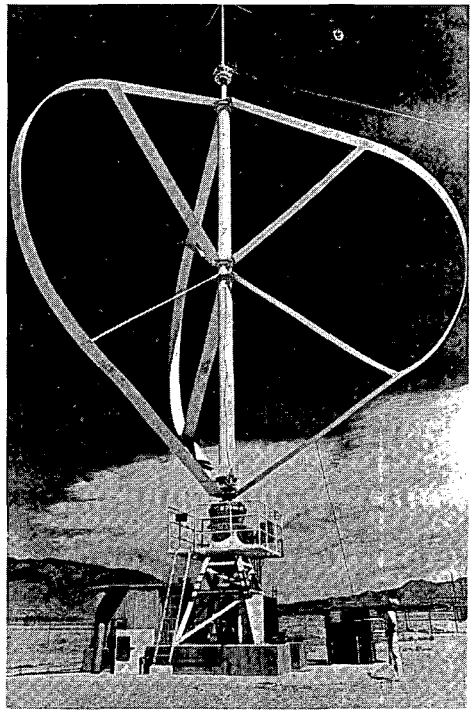
$$P \propto V^3$$

So the same machine that produces 20kW at 29 mph will only produce about 2.8kW at 15 mph and about 0.8kW at 10 mph.



Grumman Energy Systems, Inc.

These two large, utility-size wind generators have rated outputs of 15 kW (above) and 60 kW (below).



Sandia National Laboratories

Cost

Now the prospective buyers have to decide how much energy they can hope to obtain from their system, and what they are willing to pay for it. A taller tower, a larger machine, and more storage batteries will supply a higher percentage of the energy demand, but the initial investment will also be larger.

Wind machines for home use range in price from $4500 to $14,000. The tower may cost from $2000 to $5000. Depending on the amount of storage needed, battery banks range from $1500 to $4000. If alternating current is needed the system will have to have an inverter, and if the owner plans to feed excess power into the utility power grid, a synchronous inverter is needed. Labor costs for installation must also be taken into account. You can save money on do-it-yourself installation, but some experts argue for the importance of professional help, especially in putting up the tower.

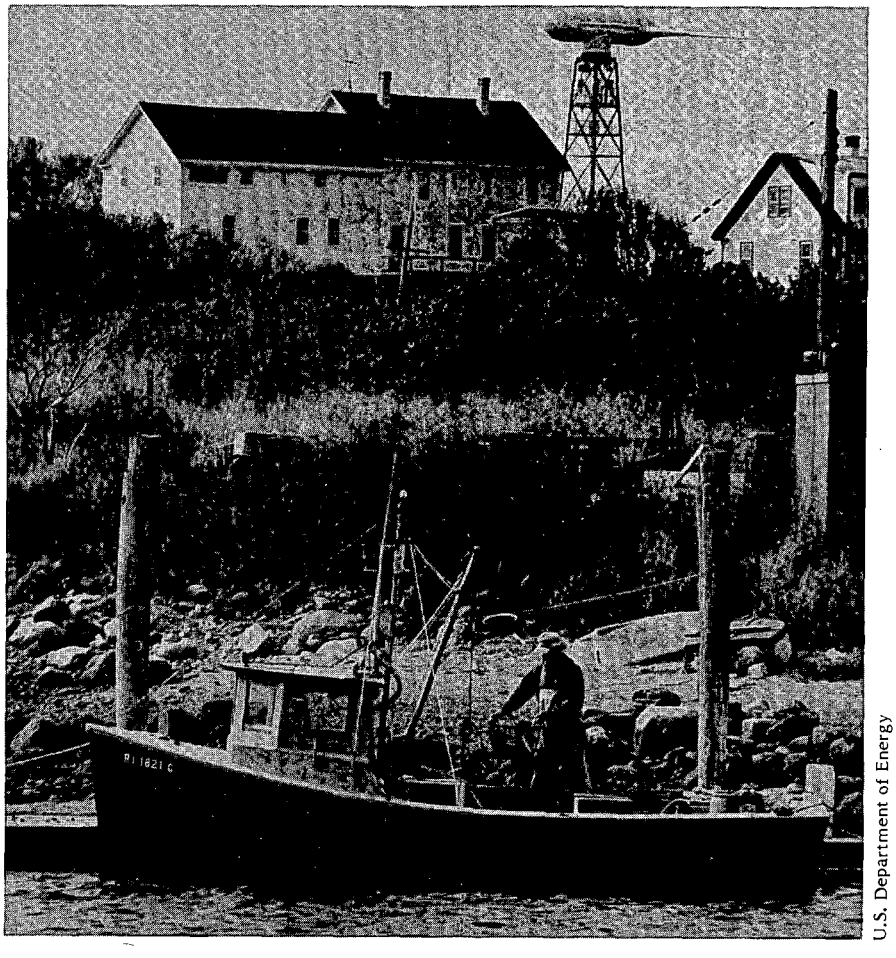
As of late 1981, a substantial Federal Energy Credit of 40% of the system's cost (up to $10,000) can be deducted from the buyer's federal income tax. Many states offer tax incentives for these systems. An additional benefit results from recent legislation requiring utilities to buy excess power generated by consumers who are linked to the power grid, although considerable utility resistance has been encountered in some localities. In some areas the utility allows the wind machine to run the electric meter backwards when it is feeding power into the grid. In other areas the wind machine's output is metered separately, and the owner is paid a percentage of the going rate.

Other Considerations

If you are weighing a wind investment, you'll need more information than can be provided here. Here are some of the points to check on in your own area.

1. Legality -- Check zoning regulations, including setback and height limits. Find out about building permits.
2. Aesthetics -- Will neighbors or family object to the size, appearance, or sound of a wind machine?
3. Reliability -- The machine you want should be available fairly locally, from a distributor who can provide immediate service and has a local reputation to maintain. Find out if parts will continue to be available for the life of the machine. You should demand, at the minimum, a one-year warranty against malfunctions. Talk to several owners of the model you're considering. Ask how often repairs are needed, what they cost, and how reliable the dealer and manufacturer are.
4. Utility interface -- What arrangement will the local utility allow for interfacing your machine with the power grid? Will that arrangement be permanent, or do they plan to change their policy?
5. Possibilities for cooperation -- Sharing the costs, risks, and benefits of a wind energy system through a cooperative, local government, group of businesses, etc. is an idea worth consideration. Group efforts may also make negotiations with the utility easier and more profitable.

Knowledgeable users and reliable manufacturers are required if wind is to make a significant contribution to the energy budget. Wind machines played a major role in energy history, however. Perhaps they will again become familiar silhouettes on the horizon.



U.S. Department of Energy

Chapter 19

Water Power

One of the most complex of the earth's sun-driven cycles is the evaporative cycle. The sun's radiation transforms the water on the surfaces of ponds, lakes, rivers, and oceans from liquid to gas. In its gaseous form, water is carried by the convection of heated air to other locations. When the air cools the water vapor condenses, clouds form, and eventually rain falls. As it collects in streams and flows downhill the water has gravitational energy and it gives up that energy, either slowly, in a smooth and gradual flow, or abruptly, in cascades and waterfalls. Wherever a dam is made to collect water, the gravitational energy the water contains is also being stored.

Vincent J. Schaefer

The many transformations of solar energy in the evaporative cycle, from radiant to thermal to kinetic to gravitational energy, give us another renewable energy source, hydropower.

Head, Flow, and New Power Output

The amount of power you can draw from a hydropower installation depends on three things: the height from which you draw the water (head), the amount of water you get per minute (flow), and the efficiency of the machine used to convert the water's energy to mechanical work or electricity.

Power = flow rate x head x efficiency

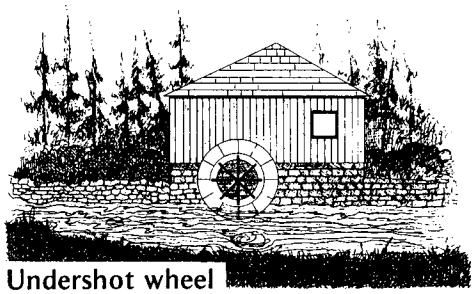
A large flow of water from a high head (Niagara, for example) contains tremendous energy. But much more modest amounts of hydropower have been used for centuries to do useful work.

Vincent J. Schaefer

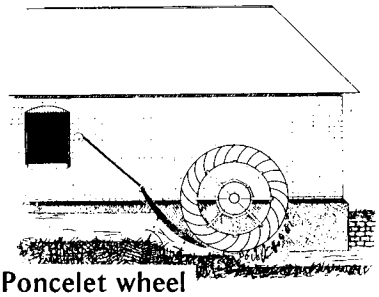
Waterwheels and Turbines

The earliest use of hydropower was for mechanical jobs, and the device used was the waterwheel. A large wheel with paddles or troughs was driven by water spouting from a spillway. The water might be directed so as to drive the lower part of the wheel with the water's flow. Such undershot wheels don't require a high water level to turn them, but they have correspondingly low efficiencies. An improvement is the Poncelet wheel with curving paddles and a tightly fitting casing to keep the flowing water trapped in the paddles. The breast wheel, similar but more complex, is designed to have the water enter at a higher level.

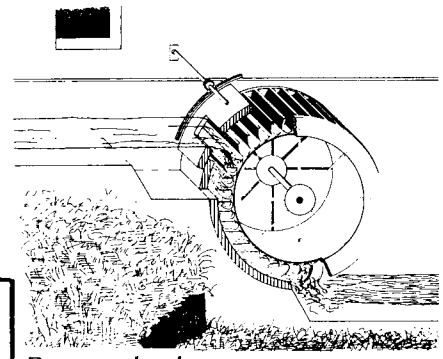
All of these undershot wheels use a combination of water velocity and mass to drive them. By contrast, the more efficient overshot wheel receives water dropped from a



Undershot wheel



Poncelet wheel



Breast wheel

higher spillway above the wheel and is turned by the weight of the water.

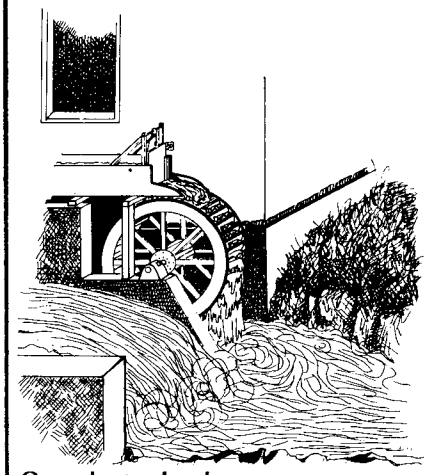
Water wheels have been used traditionally to do mechanical work: grinding grain, sawing lumber, running machinery. Their turning speeds are too slow, even when geared up significantly, to be practical for electrical generation.

The development of electricity led to the water turbine, a wheel in an enclosed casing, designed to spin much faster than the old water wheel. Two basic types of turbines emerged, to accommodate different situations.

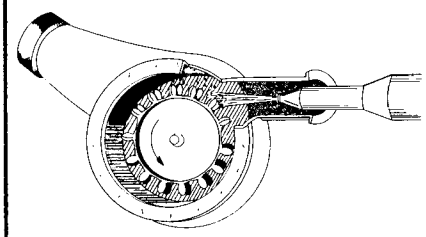
The impulse turbine is used where there is high head but not necessarily large flow. Water enters a pipe which narrows to a nozzle. The result is a high-speed jet of water which drives the cups or paddles of the impulse turbine.

In one type of impulse turbine, the cross-flow turbine, the water flows over the blades, through the hollow center of the turbine, and out the other side. The lack of resistance in this design not only produces high efficiencies, but also prevents the build-up of debris in the turbine.

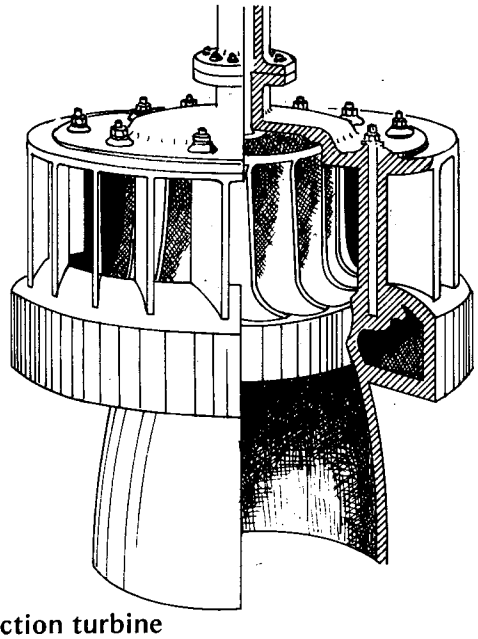
The other main turbine design is the reaction turbine. It will function with low head, because it is driven by the mass of the water rather than its velocity. The turbine itself is immersed in the flow, and the weight of the water spins the wheel.



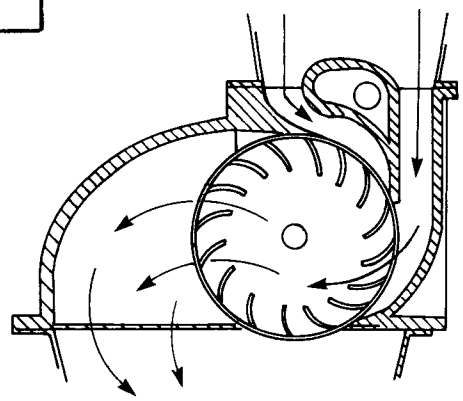
Overshot wheel



Impulse turbine



Reaction turbine



Cross-flow turbine

A Hydropower Installation

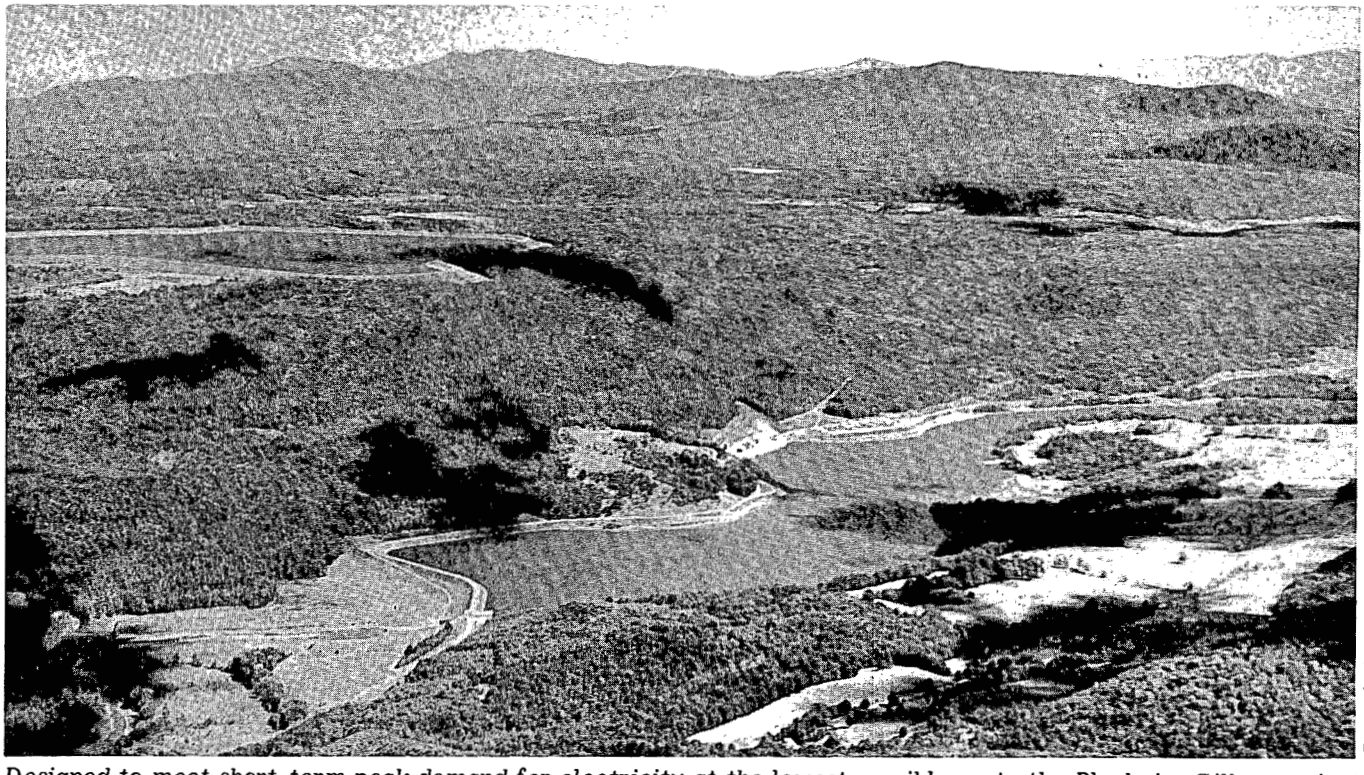
The basics of a modern hydropower installation are shown in the illustration. Where there is sufficient head at a convenient distance, a pipe is inserted in the flow at the needed elevation above the turbine. When the head is too low, a dam is used, with water drawn into a headrace. The pipe or headrace usually channels the water through a trash-rack which clears debris. The water then enters a pipe called the penstock and travels to the turbine inlet, equipped with a governor. The governor consists of valves which control the

Pumped Storage

The technique requires an upper reservoir, a lower reservoir, and generators that can work "in reverse" as pump motors. During times of low demand, excess electricity runs pumps to return water to the upper level that has fallen to the lower level. The upper reservoir then has the necessary head to meet periods of peak demand for electricity. Thus electrical energy is stored as the potential energy of the water in the upper reservoir.

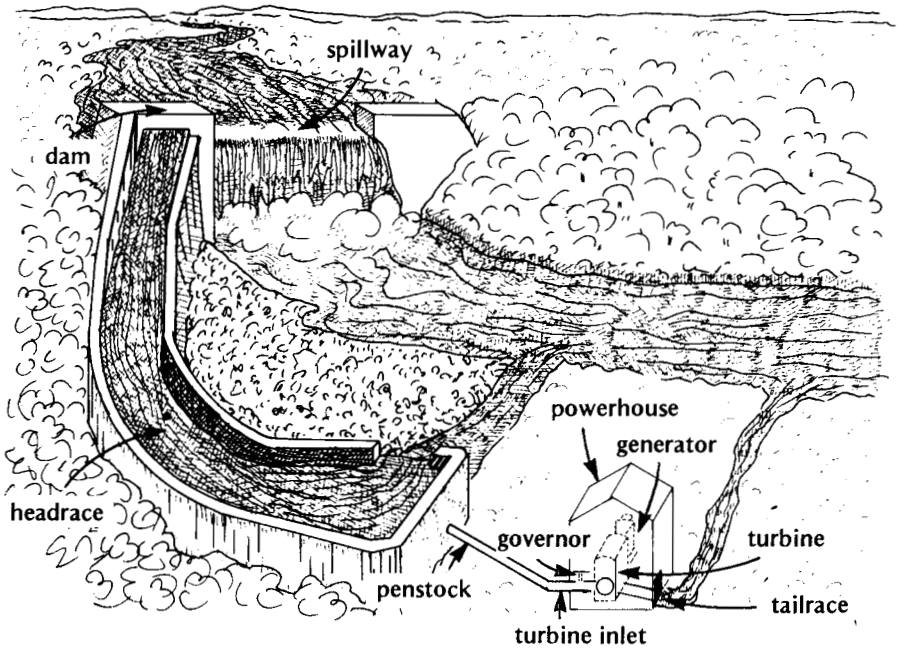
One of the difficulties with electricity is that it must be used as it is generated. A certain head and flow of water will generate a certain amount of electricity, day and night, which must be used or lost. But demand for electricity fluctuates; there are peak times when demand may exceed supply, and low times when only a fraction of the plant's generating capacity is being used.

The idea of pumped storage is to take advantage of electricity not being used in periods of low demand to increase the generating capacity for periods of high demand.



Power Authority of the State of New York

Designed to meet short-term peak demand for electricity at the lowest possible cost, the Blenheim-Gilboa project recycles water between two reservoirs connected through a powerhouse at the base of Brown Mountain in northeastern New York.



A hydropower installation

water flow to produce uniform power generation. Passing through and driving the turbine wheel or runner, the water then is returned through a tailrace to the stream or river from which it came. The power from the turbine, meanwhile, drives an electric generator. The electricity can be used as direct current to provide heat and light or to charge storage batteries. If alternating current is needed, for appliances or machinery, an inverter changes the D.C. to A.C. With the recently developed synchronous inverter it is possible to produce a regular flow of alternating current and to synchronize that current with power from the utility power grid.

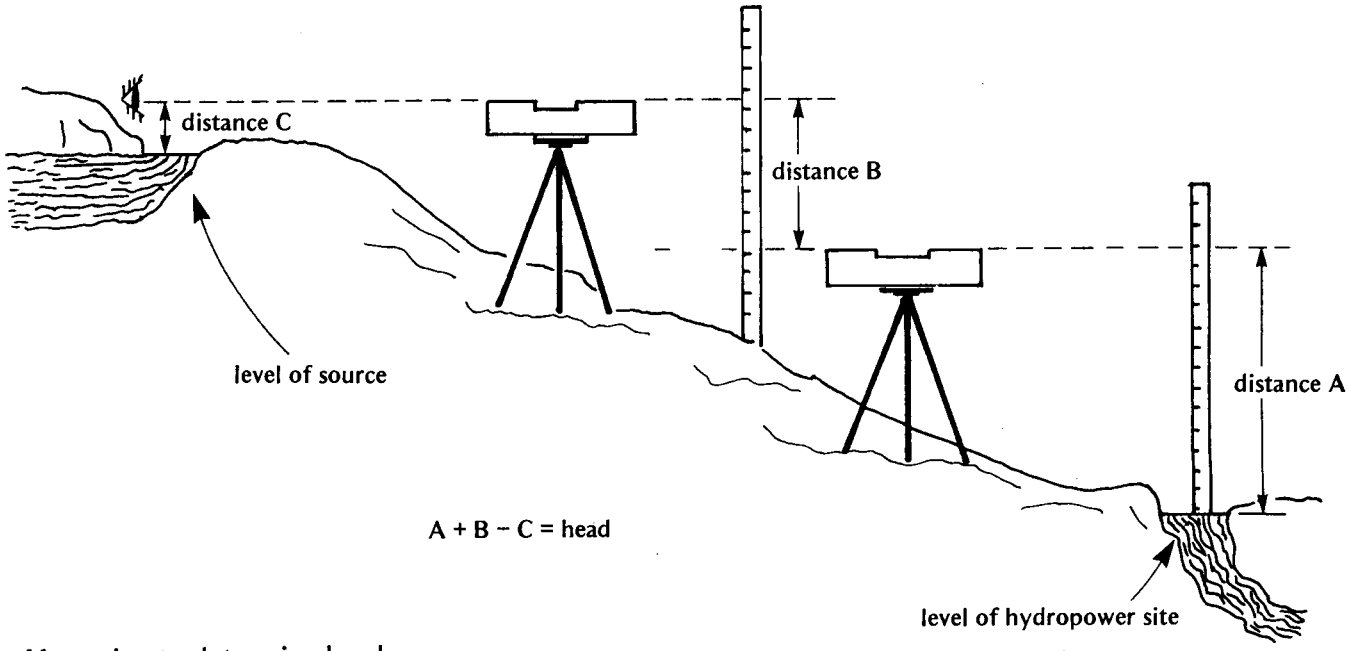
synchronous inverter: a device which converts direct current to alternating current and feeds it to appliances or to the power grid on a continuous basis.

Hydro Site Analysis

Since the amount of power you can get from a hydro facility depends on the head and flow of the available water, it's important to know the head and flow at your site. It's particularly important to have these data if you are considering buying and refurbishing old equipment, because hydropower equipment is tailored to the site. A turbine that functioned well in one setting might be worthless in another. Data should be collected for a full year, since you need to know your water's minimum and maximum head and flow.

Head is the height the water descends, from the top of the headrace to the outlet of the turbine. (Note: it is not the distance, but the vertical height that must be measured.) To determine head, it is best to use a surveyer's level and scale. If these aren't available a carpenter's level can be used, but this is a slow and tedious process.

head: the height from which water is drawn.



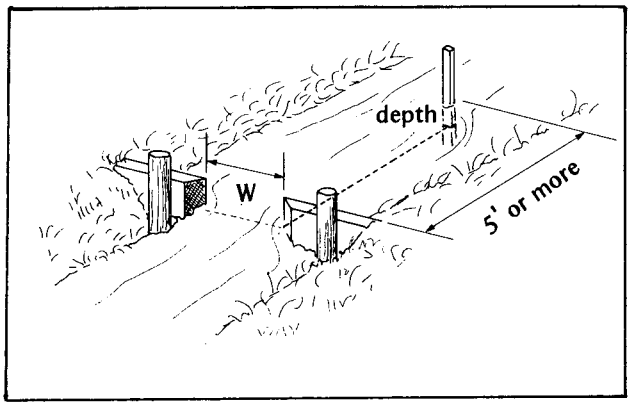
Measuring to determine head

flow: the amount of water available per unit of time.

There are various methods for measuring flow, depending on the size of the stream or river. A small stream can be channelled into a bucket. Using a timer, the flow into the bucket can be timed and the measurement converted to the appropriate unit of volume per unit of time.

For a larger stream a "weir" or board dam can be constructed with a measured slot that allows the full flow of the stream to pass through the measured area. By measuring the depth of the water as it flows through the slot and taking a reading from a "weir table" (see Chapter 19 references) an accurate measure of the flow can be determined.

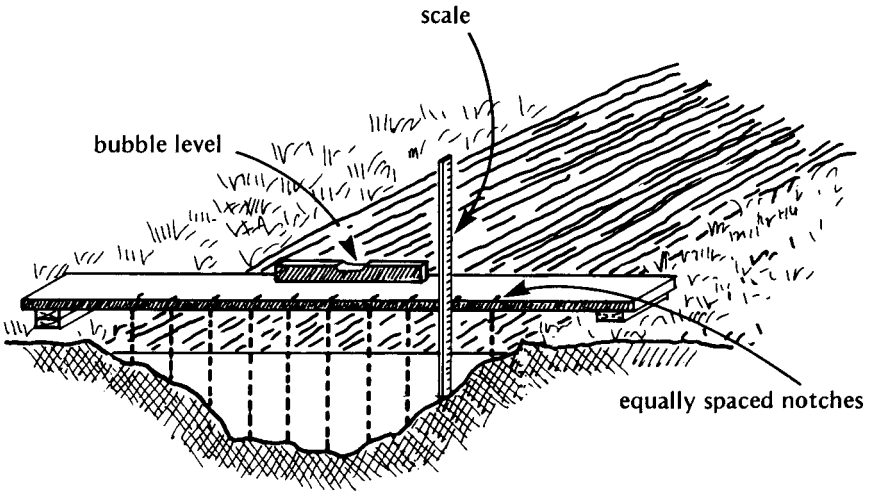
Using a weir to determine flow



Sample Weir Table

Depth on stake in inches	Cubic feet per minute per inch of slot width
1	0.40
2	1.14
3	2.09
4	3.22
5	4.50

Where the stream is too large to permit such methods a rougher estimate can be obtained by timing the speed of a float in the stream for a certain distance. The cross-sectional area is determined by taking a series of depth measurements, averaging them, and multiplying the average depth by the width of the stream. Then multiply the cross-section by the distance the float traveled to determine the volume of water that passes a given point in the measured amount of time.



Determining average depth

Of course, where the stream or river is so large that the hydro facility will only be using a part of the flow, the entrance to the headrace can be sized to allow just the desired flow.

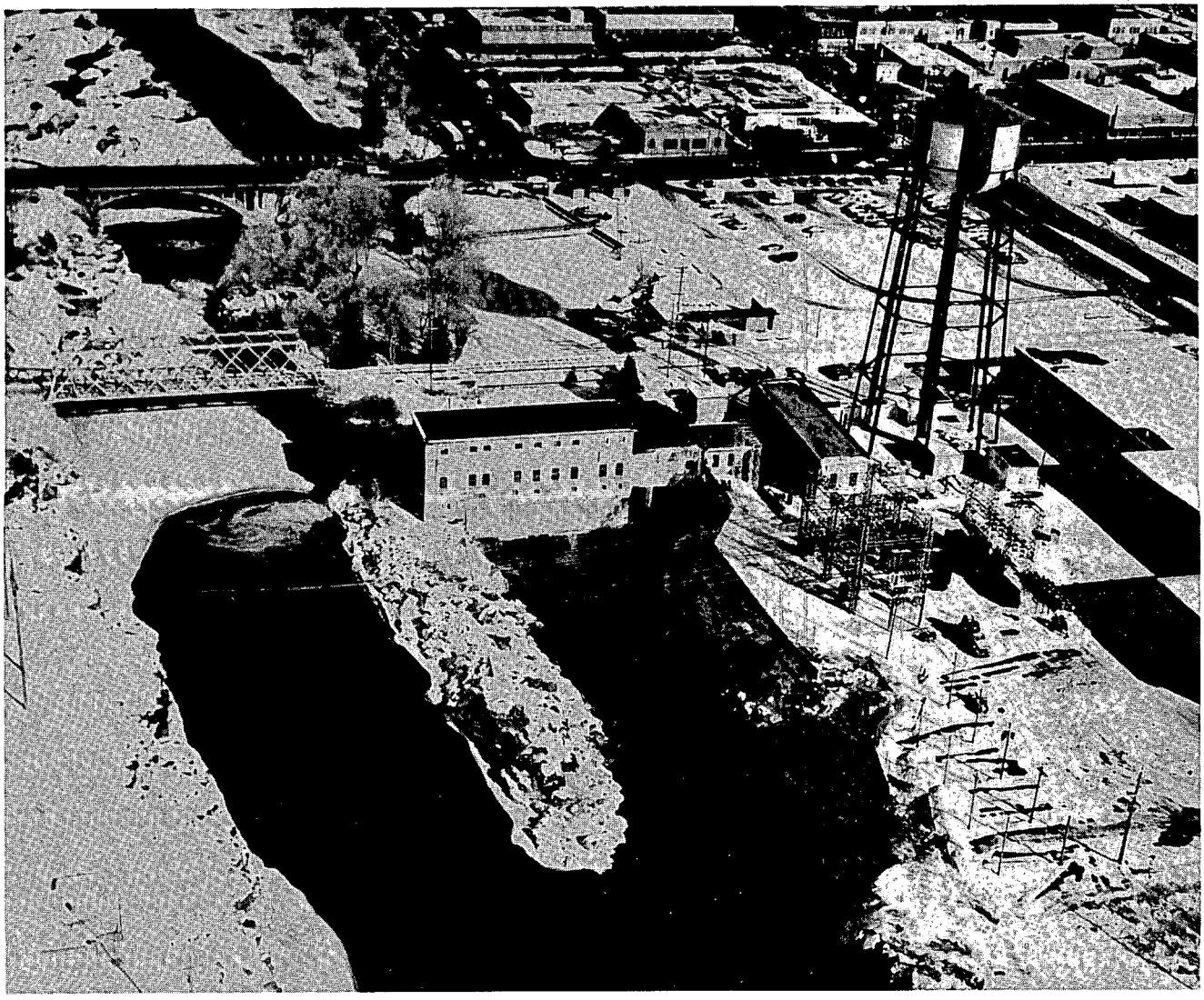
How Appropriate Is Hydropower?

Even with tax incentives, using hydropower calls for a major investment, more than $10,000 for the smallest systems. People with knowledge of hydraulics and electronics can save money by doing their own work, but the investment in time and effort will be major.

Understandably, then, the greatest activity in reviving hydropower is with communities, cooperatives, regional groups, and small companies that have the capital to support the initial costs. Many such groups are refurbishing old hydropower facilities on existing dams that were retired during the cheap fuel era. Government grants for feasibility studies have encouraged this trend.

The advantage of such revivals is that they produce new energy from hydropower without the possible environmental damage of building new dams. They also help to focus public attention on the importance of preserving the watershed -- forests, wetlands, lakes, and mountain areas -- that store rain and regulate water flow, providing a steady supply of hydropower all through the year.

watershed: the region drained by a river system.



U.S. Department of Energy

Chapter 20

Biomass: Green Energy

Donald Hegeman

There are two familiar symbols for nature's eternal renewal. We see them wherever we look: in ancient and modern art, in movies, on billboards, in children's crayoned pictures. One is the sun; the other is a growing plant. Tasseling corn, sprouting rice, ripening apples: these and like images give us a sense of hope and well-being.

It is appropriate that plants should be associated with the sun in this hopeful symbolism, because plants are major collectors, processors, and storers of solar energy. In this context plants and plant products and residues are called "biomass", a term used to describe all the earth's organic matter, containing solar energy stored in chemical form through the process of photosynthesis.

It is that phrase "stored in chemical form" that is the key to the special potential of biomass. Biomass -- wood, hay, corn, kelp, organic waste, whatever its form -- stores solar energy chemically. And through various processes, that chemical energy can be transformed to solid, liquid, and gaseous fuels that can be burned directly or easily stored and transported.

Traditional Energy Uses for Biomass

Before we consider modern processes for extracting energy from biomass, we should recall that the use of biomass for energy is as old as life itself. Food is biomass, and is the source of all the muscular and mental energy of the animal world. When we consider the many centuries when human and animal muscle, fueled by biomass, did the work of civilization, the era of fossil fuels seems short indeed.

It is important to keep food in focus as the primary energy product of biomass, because the world food picture is deteriorating even as the world's energy problems worsen. Although food production has continued to grow, it has not kept pace with population. The last few years have seen a number of countries, especially in Africa and Asia, move from the list of food exporting nations to that of food importing nations. For reasons of both compassion and politics, biomass must be seen first as fuel for bodies rather than for machines.

R. A. Fogarty

Farming the Sea

A large percentage of the world's biomass is found, not on land, but in the water. Although we do not now obtain a large percentage of our diet from the plant and animal life of the sea, there is room for expansion. Modern intensive fishing methods have depleted fish populations, and environmental insults such as oil spills and dumping have polluted the best waters of many areas. At the same time, however, research is going on in aquaculture and mariculture with the goal of greatly increasing the food yield of ponds, estuaries, and coastal waters. Ocean thermal energy conversion facilities (see Chapter 21), which bring deep water nutrients to the surface, may be developed both as centers for mariculture and as floating power plants.

Edward Lalor

The New Alchemists have developed high-yield fish farming in ponds, in tanks, and under domes.

Biomass also feeds the soil. Serving as fertilizer and compost, plant residues and manure fuel the growth of new plants by providing nutrients. Soil is not an easily renewed resource, and is constantly being eroded, reduced, and leached of its nutrients. In providing constituents for new soil, the earth's biomass is carrying out its natural function, which is to sustain itself. Although compost and manure might not be generally thought of as fuels, they certainly provide irreplaceable energy for the cycle of world biomass production.

compost: a mixture of decaying organic matter.

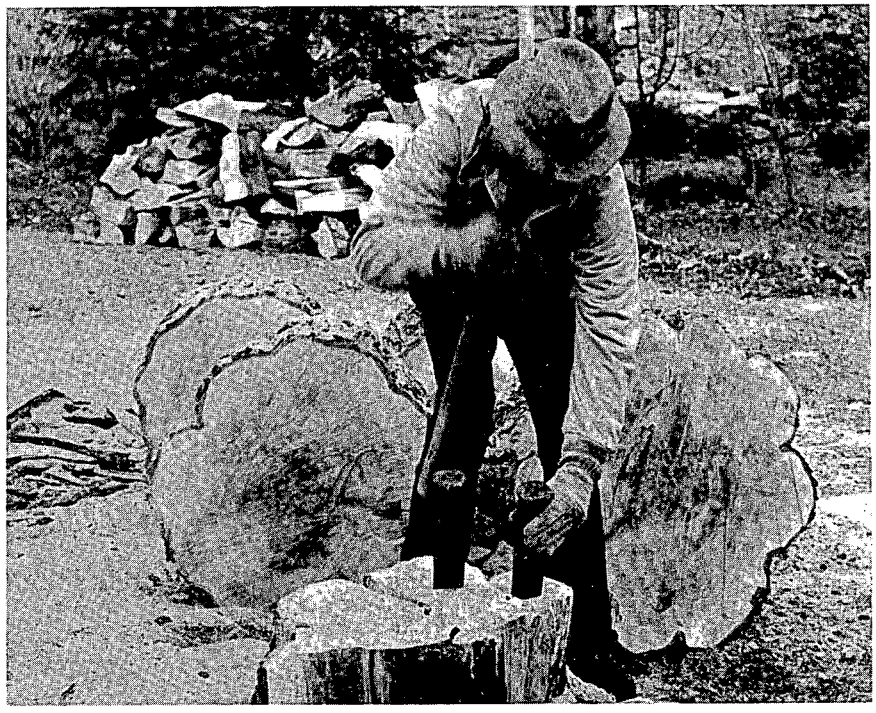
manure: animal dung used to enrich soil.

Food to nourish animal life and soil to nourish plant life: in any discussion of biomass energy development it should not be forgotten that the need for these basics will always exist and must be met.

Burning Wood

Wood is the world's foremost biomass fuel. Forty percent of the world's people use wood as their primary fuel for heating and cooking. Partly a reaction to rising fuel

costs, partly a reassertion of the need for independence, the recent resurgence of the wood stove in the United States has become a notable phenomenon. Many homes, especially in rural America, never abandoned the wood stove for fossil fuels. But wood burning is increasing so rapidly that some experts estimate that wood contributes more than nuclear fuel to this nation's energy budget. Use of wood for residential heat has more than doubled in the last ten years. This growth reflects both improved efficiency in wood stove and wood furnace designs and changing consumer attitudes.



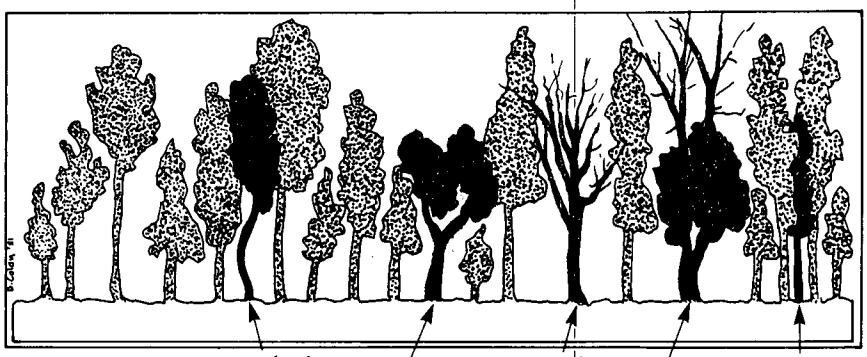
Michael Fogarty

Residential use is not the only area of growth for wood fuel. The wood industry has become increasingly energy self-sufficient through the use of wood waste as fuel. Some municipalities are also using direct combustion of wood or organic wastes, either for heat or for electric generation.

In much of the developing world, wood has always been the number one fuel. The problems being experienced in some of these nations help dramatize certain concerns about wood burning. The case of Central Africa has become a source of world concern. As a growing population has stripped the forests for fuel and herds have overgrazed the grasslands, the Sahara Desert has actually expanded, reducing the land available for either trees, grazing, or crops. Energy demand has created not only an energy problem but an acute food crisis.

Starvation in the Sahel may seem a far cry from wood stoves in the United States. But the case of Central Africa raises an important point regarding the use of wood, or any form of biomass, for fuel. Biomass is one of the "slower" forms of renewable energy, so that there are certain natural limits to how fast it can be harvested without damage to the resource base. This means that management is necessary, to control demand and monitor the impacts on soil, water supply, and new growth.

Sahel: the drought-afflicted area of the southern Sahara in West Africa.



Types of trees to harvest

Air quality is another factor to consider. Burning biomass doesn't put as much sulfur dioxide into the air as fossil fuels do, but it does produce other harmful gases and particulates. Hardwood, well-dried, gives the cleanest burn in a wood stove. A high-temperature burn with a sufficient air supply makes for more complete and therefore cleaner combustion. Some companies are producing catalytic converters for wood stoves to help remove the pollutants from wood smoke.

particulates: small soot and ash particles produced by combustion.

catalytic converter: a device which reduces pollution from burning.

CHARACTERISTICS OF COMMONLY BURNED WOODS

Species	Split-ability	Ease of Starting	Heavy Smoke	Sparks	Coaling Qualities
Apple	Hard	Hard	No	Few	Excellent
Ash	Medium	Fair	No	Few	Good
Beech	Hard	Hard	No	Few	Excellent
Birch	Medium	Easy	No	Moderate	Good
Cedar	Easy	Easy	Yes	Many	Poor
Cherry	Medium	Hard	No	Few	Excellent
Cottonwood	Easy	Easy	Medium	Moderate	Good
Elm	Hard	Fair	Medium	Few	Good
Hemlock	Easy	Easy	Medium	Many	Poor
Hickory	Medium	Fair	No	Moderate	Excellent
Locust, Black	Hard	Hard	No	Few	Excellent
Maple	Medium	Hard	No	Few	Excellent
Oak	Hard	Hard	No	Few	Excellent
Pine	Easy	Easy	Medium	Moderate	Fair-Poor
Poplar, Yellow	Easy	Easy	Medium	Moderate	Fair
Spruce, Norway	Medium	Easy	Yes	Many	Poor
Sycamore	Medium	Fair	Medium	Few	Good
Tamarack (Larch)	Easy	Easy	Medium	Moderate	Good
Walnut	Medium	Fair	No	Few	Good
Willow	Medium	Fair	No	Moderate	Poor

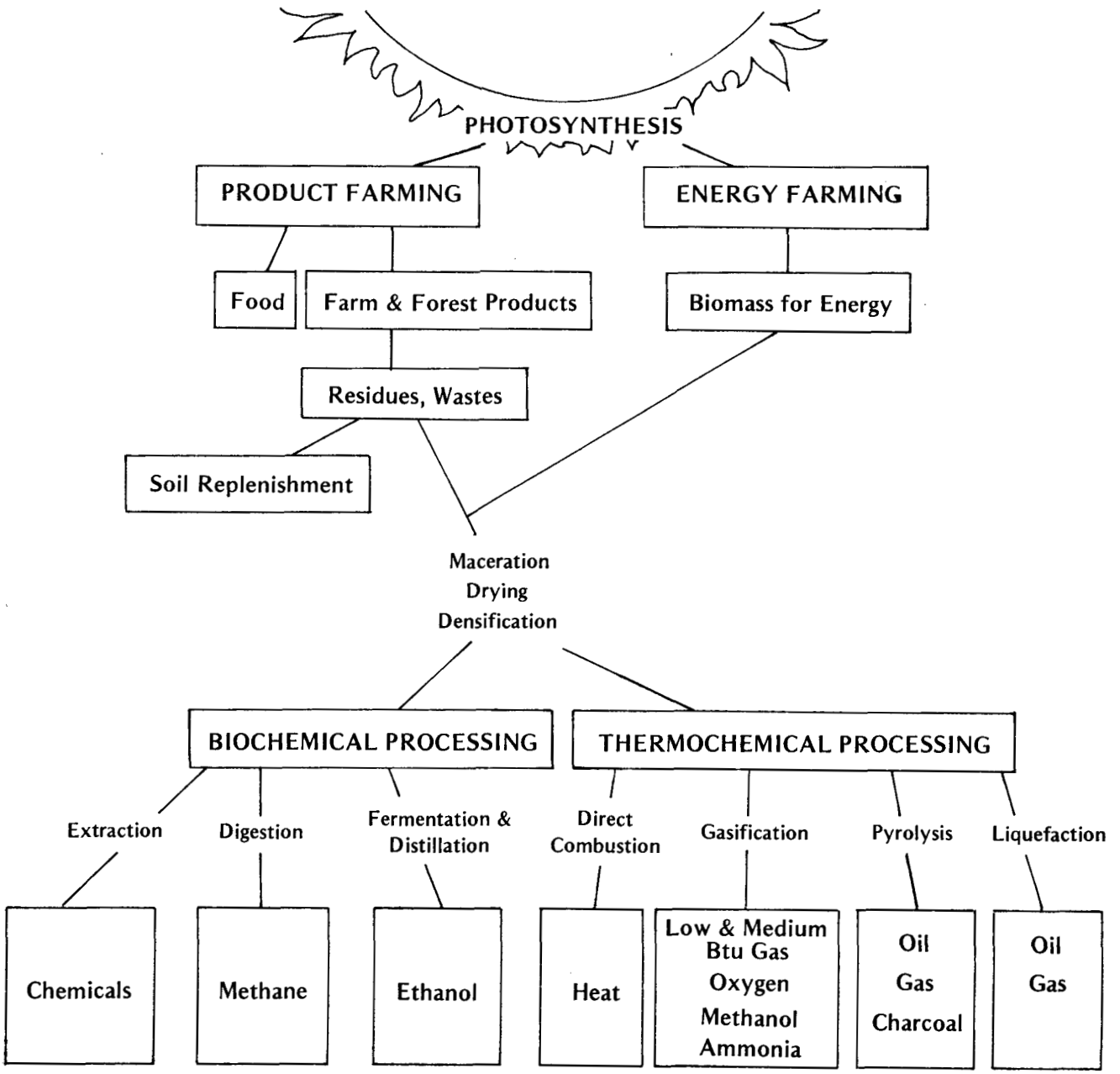
Finally, safety is a consideration. A wood-burning stove in the house presents hazards for which the uninformed, and especially children, may not be prepared. As the number of wood stoves has increased, so has the incidence of house fires due to improper wood stove installation and use. Plenty of information is available to help consumers avoid these tragedies.

In spite of these cautions, a wood stove or furnace can be an overall benefit for the homeowner, community, or industry with a wood supply. From the standpoint of economy and energy independence wood is a plus in the energy budget.

Now let's consider some other biomass fuels and how they are produced.

Developing Energy Uses for Biomass

In a world heavily dependent on liquid and gaseous fuels, it is not surprising that liquid and gas biomass fuels would excite strong interest. How are these fuels produced from biomass? Most biomass fuel production processes fall under one of two headings; biochemical or thermochemical. In the first, enzymes, fungi, or microorganisms perform work on the biomass feedstock. In the second, the feedstock is broken down by a controlled heating process to produce fuels.



Ethanol

Ethanol, a liquid fuel, is commonly called grain alcohol, but grain is only one of its possible feedstocks. In Brazil, one of the world's largest ethanol consumers, sugar cane is used. Theoretically almost any agricultural crop containing starch can be used, but the producer has to consider yield and production cost per acre, as well as other crop-specific factors like ease of storage, related soil erosion, water demand, and climate. Sugar cane gives an excellent yield per acre but demands a tropical or sub-tropical climate. Corn has a relatively low cost per acre but is demanding of water and tends to cause soil erosion. Sweet sorghum is regarded as having good potential for ethanol production because it will tolerate a wide range of climates and soil types, but it is unfamiliar to many farmers and is still in the experimental stage. Food processing wastes are a low-cost feedstock for ethanol fuel.

feedstock: the raw biomass that is converted to one or more energy end products.

U.S. Department of Energy

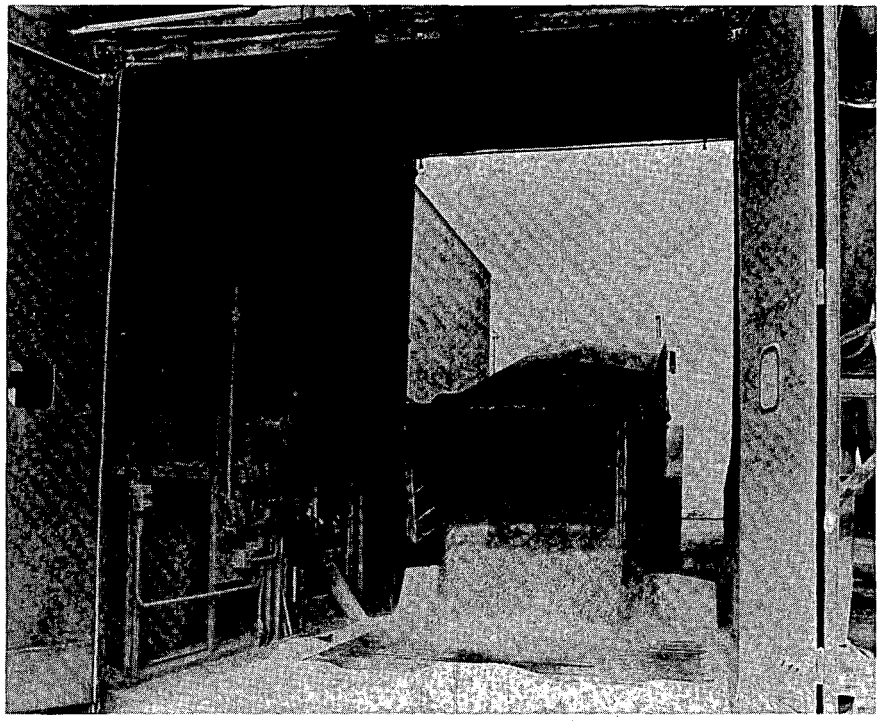
Hawaii, the nation's largest producer of sugar cane, is already using cane wastes as fuel for sugar refining and electrical generation.

Another factor to consider in choosing a feedstock is whether the wastes or byproducts will be useful and help to pay for the processing. Sugar cane crop residue can be used as a fuel in the fermentation process. Grains yield a high-protein feed after processing that is suitable for livestock. Further research on ethanol byproducts could increase their value and use.

Ethanol is produced by the biochemical process of fermentation. The ground feedstock is cooked and enzymes are added which reduce the starches in the feedstock to simple sugars. Solids are separated out, and yeast is added to the remaining liquid mash. In the absence of oxygen, the yeast works on the sugars to produce alcohol. The liquid then is distilled to concentrate the alcohol.

fermentation: the breaking down of carbohydrates to produce CO_2 and/or acid.

distillation: the evaporating and recondensing of liquid mixtures to separate various liquids by their boiling points.



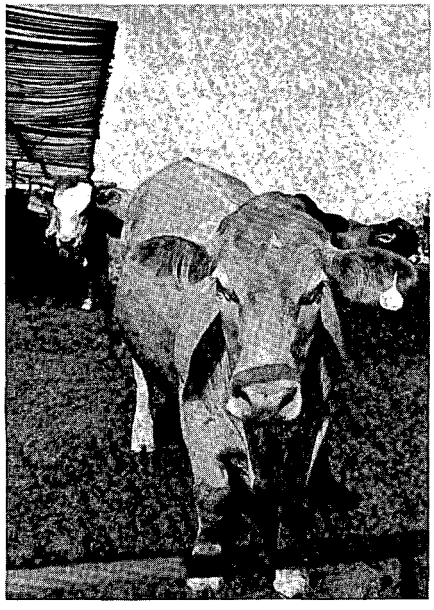
U.S. Department of Energy

The grain being delivered to this Illinois distillery will become alcohol for gasohol.

Ethanol can be used pure, as an automotive fuel, or added to gasoline to make gasohol. Ethanol raises the octane of gasoline, making it an attractive alternative to other methods for boosting octane. It can also be used as a chemical feedstock.

Methane

Natural gas, drawn from underground pockets in the areas of oil and coal deposits, begins with biomass: organic matter decomposing over many centuries. Methane production is a similar but accelerated process, using a methane digester to process organic wastes and manure, yielding methane gas in a matter of days.



Pacific Gas and Electric

The wastes from this feedlot provide methane gas for a West Coast utility company.

The digester is a container which allows bacteria to break down organic wastes in the absence of oxygen. The container is constructed to allow feeding in and mixing of wastes, and drawing off of both "biogas" and its useful byproducts. The biogas produced is actually methane, carbon dioxide, and other gases, in varying ratios. The byproducts, effluent and sludge, are good fertilizers and soil conditioners.

effluent: liquid waste from a process.

sludge: semisolid waste from a process.

Methane digestion is now being seen as a way of disposing of organic wastes, sewage, and unwanted plants like water hyacinth, while producing a useful fuel to supplement natural gas supplies.

Thermochemical Products

The purpose of thermochemical processes is to break down raw biomass into gases, liquids, and solids that can be used as fuels. This is done by applying heat but limiting oxygen supply. Of course, if oxygen were abundant in the

process, the materials would oxidize when heated -- that is, they would burn. By limiting or cutting off oxygen entirely, the biomass is broken down without being consumed in the process.

One example is destructive distillation, in which wood is heated in the absence of oxygen, yielding fuel gas, and a liquid alcohol fuel, methanol, among other products.

Another thermochemical process is pyrolysis. By heat, organic matter is broken down into fuel gas, heavy fuel oil, and char, a solid which can also be burned as fuel.

Cogeneration

Cogeneration means the integration of two systems in order to use waste energy from one system to drive the other. Some systems need high quality energy to function, but after the energy passes through the system it is not completely spent, and can still do jobs that require lower quality energy.

Steam powered electric generating plants, for example, use high temperature steam to drive turbines. After the steam is used to generate power it can be used for space heating or an industrial process.

Pacific Gas and Electric

Municipal garbage can be burned directly as a fuel, pyrolized to yield gas and fuel oil, or digested to produce methane.

Wastes as Fuel

As with cogeneration, waste materials from one process can be used to fuel another process, like corn or sugar cane wastes being used as fuel for distilling ethanol. Using wastes as fuel is not really cogeneration (the use of waste energy), but the two processes are similar in purpose. In both, the goal is to conserve energy by taking advantage of resources that in the past would have simply gone up the chimney, down a sewer, or into a landfill.

Each person generates about 1400 pounds of trash per year. These wastes, along with agricultural wastes, represent a major energy resource. Many cities are finding that municipal trash can be turned into a financial asset, replacing fossil fuels in local steam heat or electric generating plants.

Biomass Potential and Problems

The possibilities for biomass energy development are so vast that such a brief treatment as this can only scratch the surface. Certain common factors do emerge, however.

In general it can be said that biomass energy has the following advantages:

- it is a renewable form of energy that can be stored;
- the technologies for producing it are fairly well-developed;
- its production can help to recycle polluting wastes;
- it reduces dependence on nonrenewable and more polluting fossil fuels.

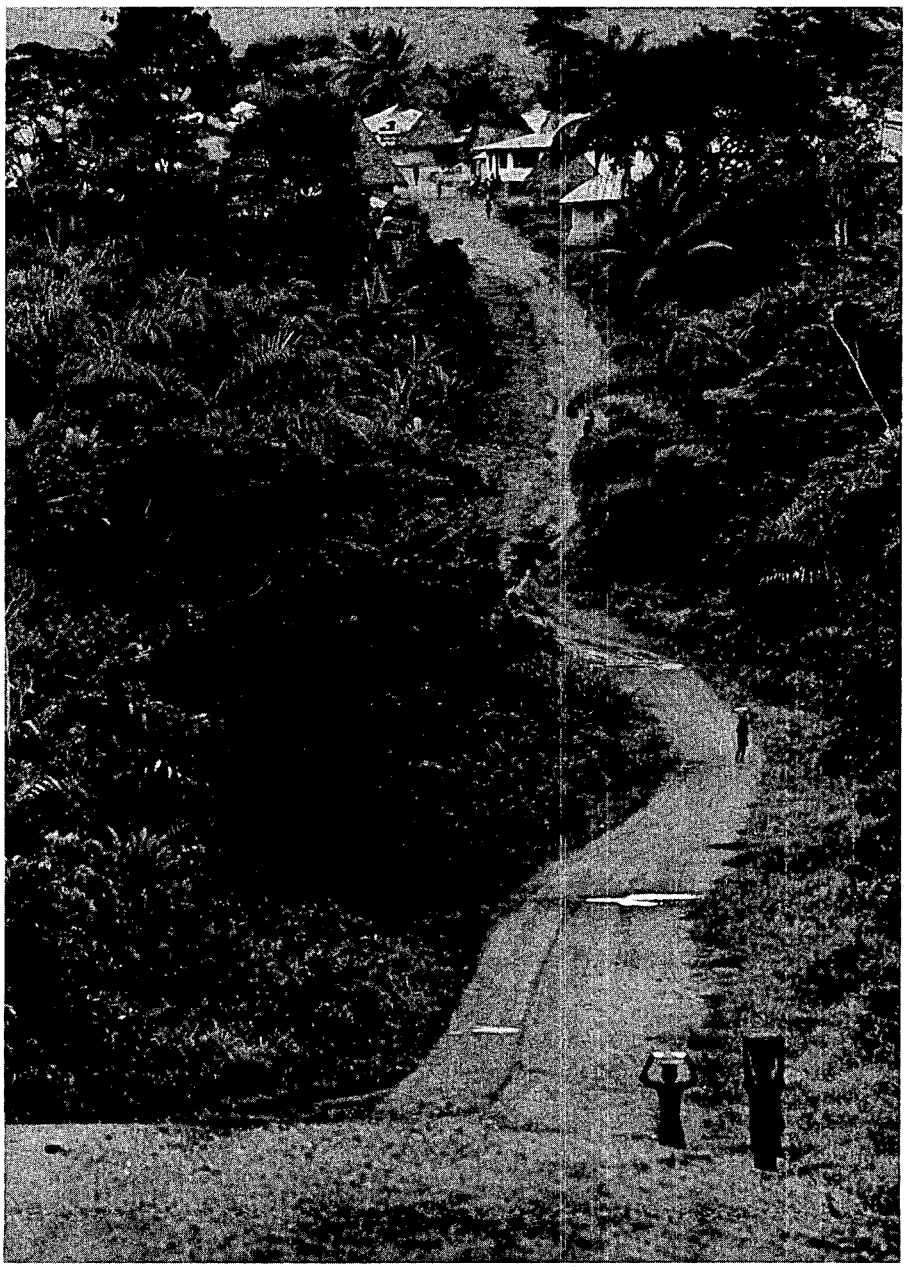
Most of the concerns about biomass energy development fall under three headings:

- the concern that producing biomass fuels will consume more fossil fuel than it replaces.
- the fear that using biomass for fuel will drive up the price of food, because of competition for agricultural products and land, and
- the fear that biomass energy development will have serious and unpredictable environmental effects (such as a change in the amount of carbon dioxide in the atmosphere).

Both the promise of biomass, and the concerns raised by its development, seem to argue for a program of well-controlled, well-managed experimental development. The use of industrial, agricultural, and municipal wastes for fuel should be encouraged, since this saves money and reduces pollution. Keeping fuel production and consumption close to the source of biomass could save on energy transportation and help create jobs and industry in rural areas.

It is critical that biomass fuel production not become a drain on dwindling fossil fuel supplies. In terms of energy economy, it makes more sense to burn biomass directly to generate power than it does to use natural gas to fuel the distillation of ethanol, for example.

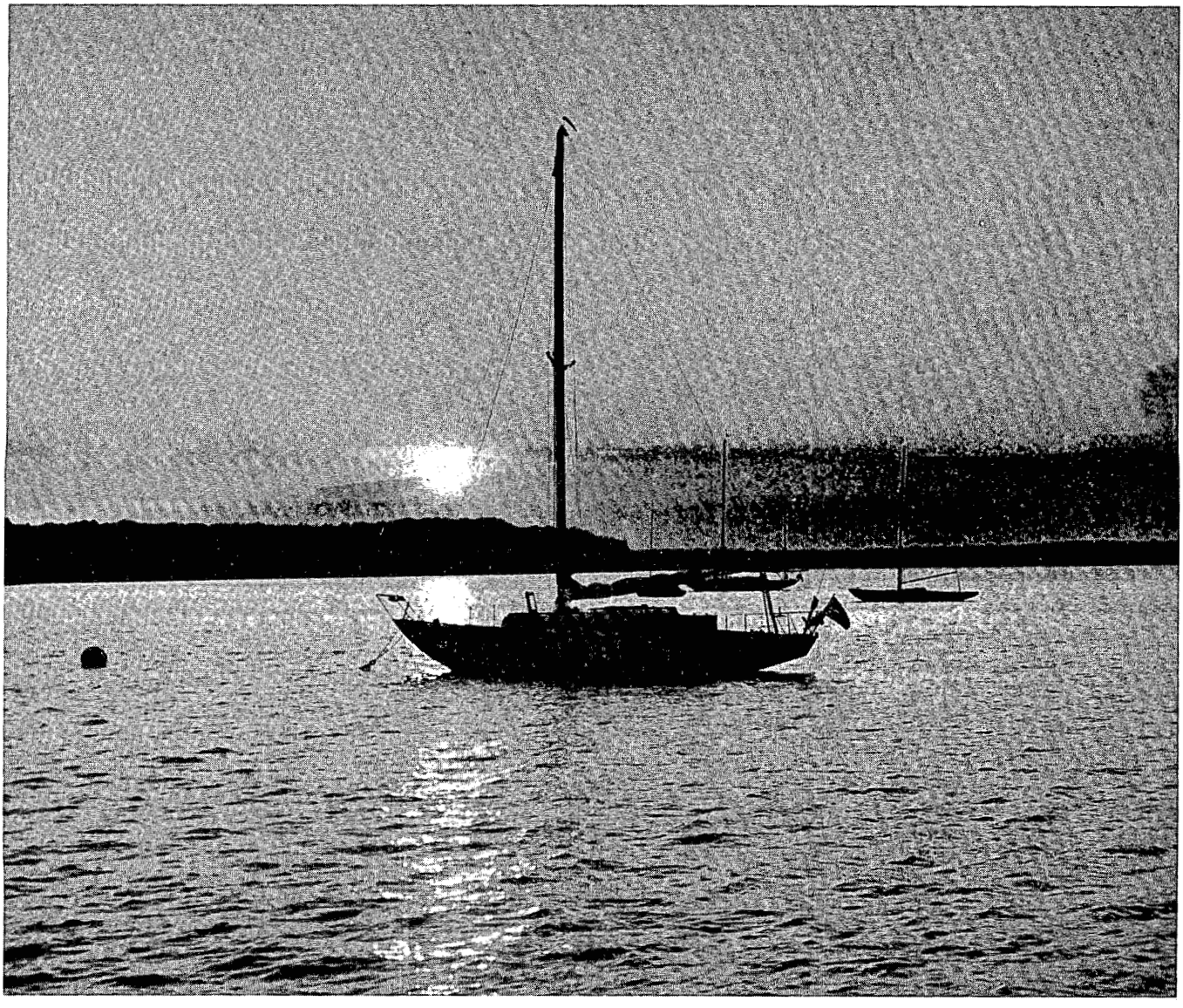
Most important, farmers, foresters, industrialists, and government planners must never see biomass simply as a source of energy. Biomass is, in fact, a very thin layer of organic matter on the surface of the earth. But that thin layer regulates the flow of water, the recycling of gases, and the renewal of soil on the planet, making life on the earth possible.



Donald Hegeman

Chapter 21

Energy from the Earth and Ocean



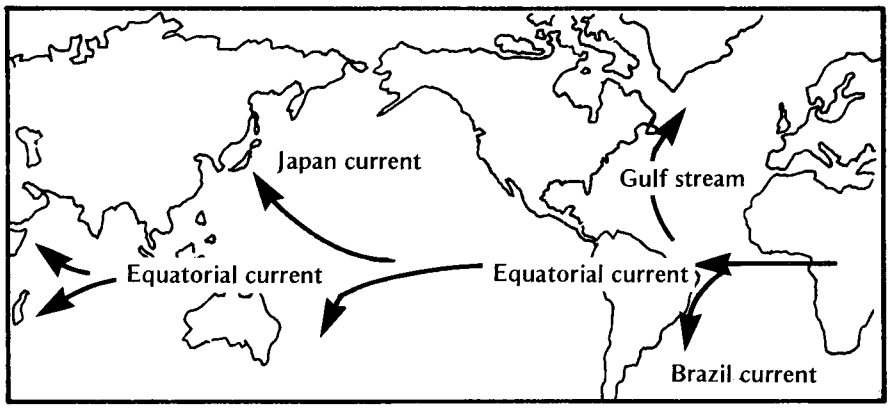
N.Y.S. Department of Commerce

Before closing this survey of solar energy, we will briefly examine three more energy technologies. These technologies are well understood and have been effectively employed, although not necessarily in the United States. Only one is truly a solar technology but all three deserve our attention because, as "alternative technologies" they have received less than their share of attention in the past, and they offer major supplies of renewable energy for the future.

Ocean Thermal Energy Conversion

Water covers three quarters of the earth's surface. In fact, it covers a full nine tenths of the regions which receive the most solar radiation: the latitudes from the Tropic of Cancer to the Tropic of Capricorn. So a great deal of solar

energy falls on, and is absorbed by, the surface waters of the oceans. The deep waters of the oceans tend to be much colder. In the tropics, for example, surface water temperatures average 25°C (77°F) while deep waters are about 5°C (41°F). Ocean thermal energy conversion (OTEC) makes use of this temperature difference to drive a heat engine.



Warm currents of the world

A heat engine can extract mechanical energy from the flow of a heated fluid from a warmer to a cooler region. This is the principle on which a steam-powered electric generator works. The efficiency of the engine is proportional to the difference between the hot source and the cold source.

$$\text{Maximum efficiency} = \frac{T_1 - T_2}{T_1}$$

where T_1 is the temperature of the hot source and T_2 is the temperature of the cold source, measured in degrees Kelvin.

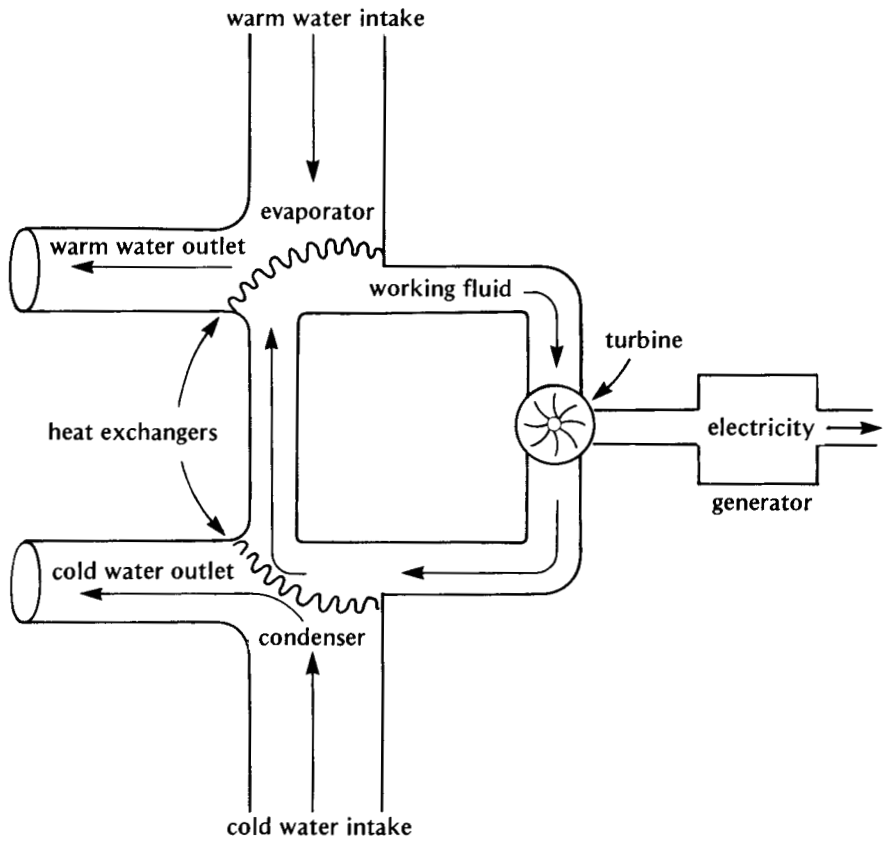
It's obvious from this equation that a heat engine that is driven by the temperature differences of the ocean will have a low efficiency, about 7% at best. Such a low return would be unacceptable from a limited, nonrenewable energy source like oil or gas. The solar heat stored in the ocean is an enormous resource, however, is present day and night, and is constantly being renewed.

It is this enormous resource that OTEC exploits. The first experimental OTEC plants were tested during the 1920's and 30's, and an operational demonstrator is now located in Hawaii.

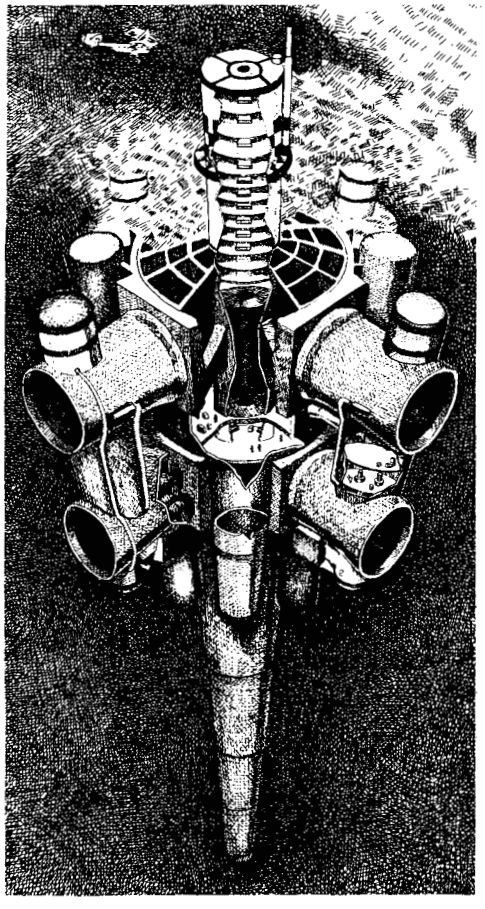
The engine circulates a working fluid with a low boiling point and a high vapor pressure, such as freon, ammonia, or propane. As it absorbs heat from warm surface water through a heat exchanger, the fluid vaporizes. The vapor, under pressure, drives a turbine to generate electricity. After passing through the turbine the spent vapor gives up

working fluid: fluid circulated in a closed system.

heat through another heat exchanger to cold, deeper water. The loss of heat condenses the working fluid, which is then ready to begin the cycle again.



Ocean thermal energy conversion



OTEC Development

Ocean thermal energy conversion is a technology requiring a major initial investment. Stations at sea (in the Gulf Stream, for example) offer the best output, but problems of how to moor the stations and how to transmit the electricity have to be solved. One suggestion is to use the generated electricity to produce hydrogen, a very versatile fuel, from the surrounding sea water. The hydrogen could then be shipped, instead of electricity having to be transmitted.

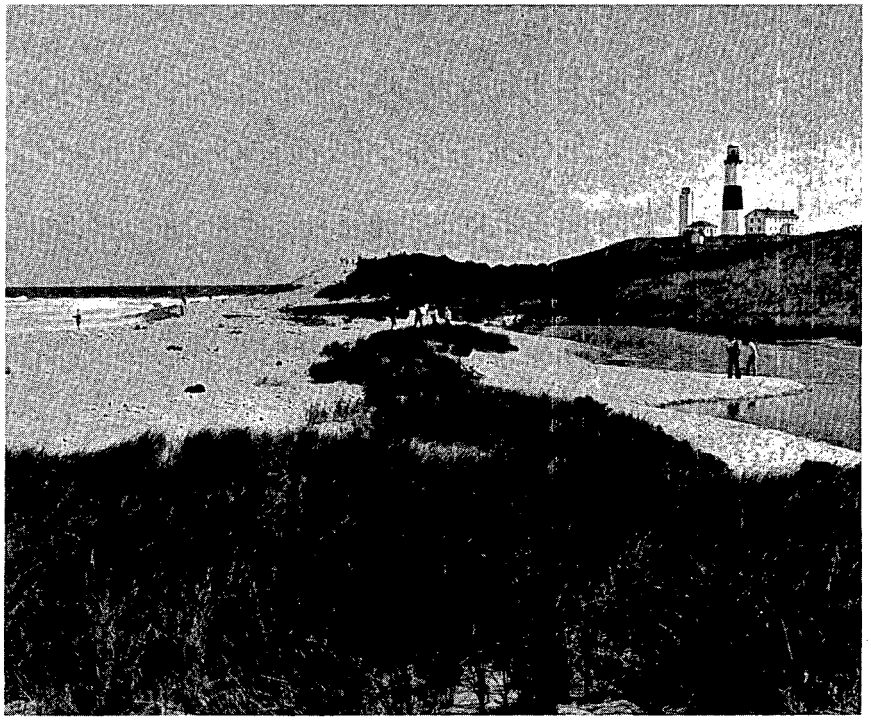
Hydrogen Fuel

To many, hydrogen seems to hold out the promise of a clean, portable, and convenient fuel. Although it can be produced by coal gasification and other thermochemical methods, the more common method is the electrolysis of water. With a low voltage, water molecules can be made to dissociate into hydrogen and oxygen. The hydrogen can be attached to metallic compounds under pressure to form hydrides for storage, or can be transported by pipeline like natural gas. When burned as a fuel, the hydrogen recombines with oxygen to produce water vapor.

Ocean thermal differences offer an enormous and constant source of power. While the efficiency of OTEC is not high, the free and continuous supply of fuel may well outweigh the efficiency factor, making OTEC a good energy development investment. The OTEC process will change surrounding water temperatures slightly. Development of OTEC will, therefore, need to include a study of the possible environmental effects.

Tidal Power

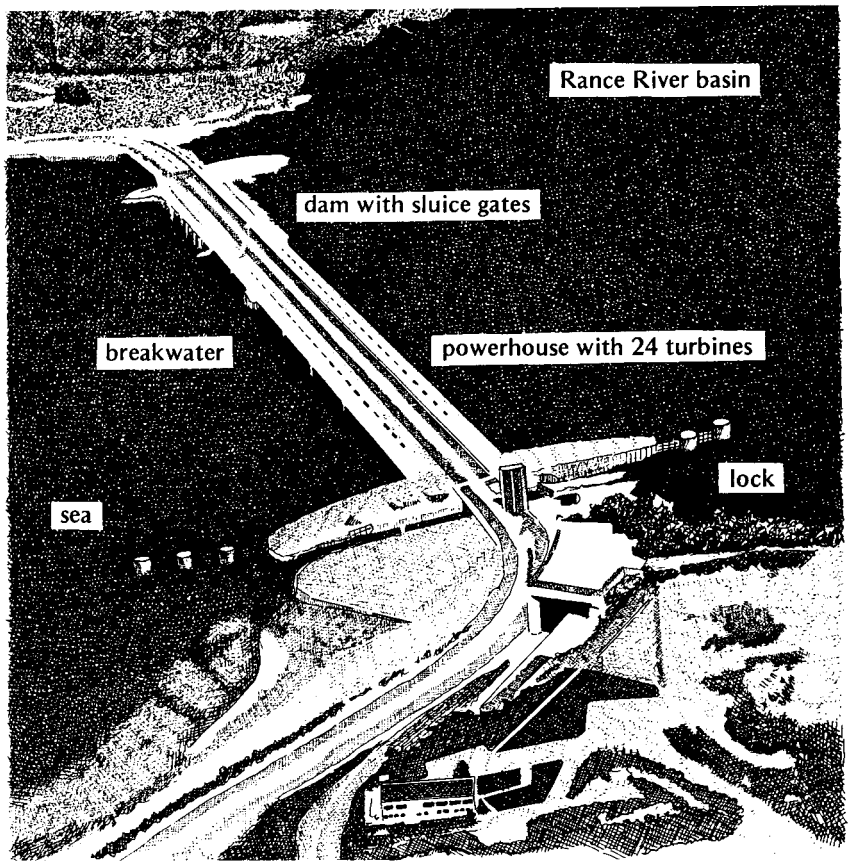
Tides are caused by the rotation of the earth within the pulling magnetic fields of the moon and sun. The rising and falling tide was used in the Middle Ages to turn mill wheels. Today France and the Soviet Union have large tidal power projects, and China has developed many such projects on a smaller scale. The technology is well understood, fairly simple, and appears to have only minor environmental effects.



N.Y.S. Department of Commerce

What is needed for exploitation of tidal power is a narrow estuary or bay with a significant "tidal range." (The Rance River project in France, for example, has high tides of 9 to 14 meters above the low tide.) The estuary into which the tide flows is crossed by a dam with sluices. The sluices are opened for the incoming tide, but closed at high tide. The tide then works like water above a dam in a hydropower facility, driving turbines to produce electricity as it flows out to join the outgoing tide. In some projects the turbines are reversible, and can be driven by both the incoming and the outgoing tide.

sluice: a gate used to control the flow of water.



Rance River Tidal Project, Brittany

Is the cost of damming a large area and installing expensive lowhead turbines balanced by the assurance of renewable, nonpolluting power? This is the judgment investors and governments must make in weighing tidal power as an energy option.

Geothermal Power

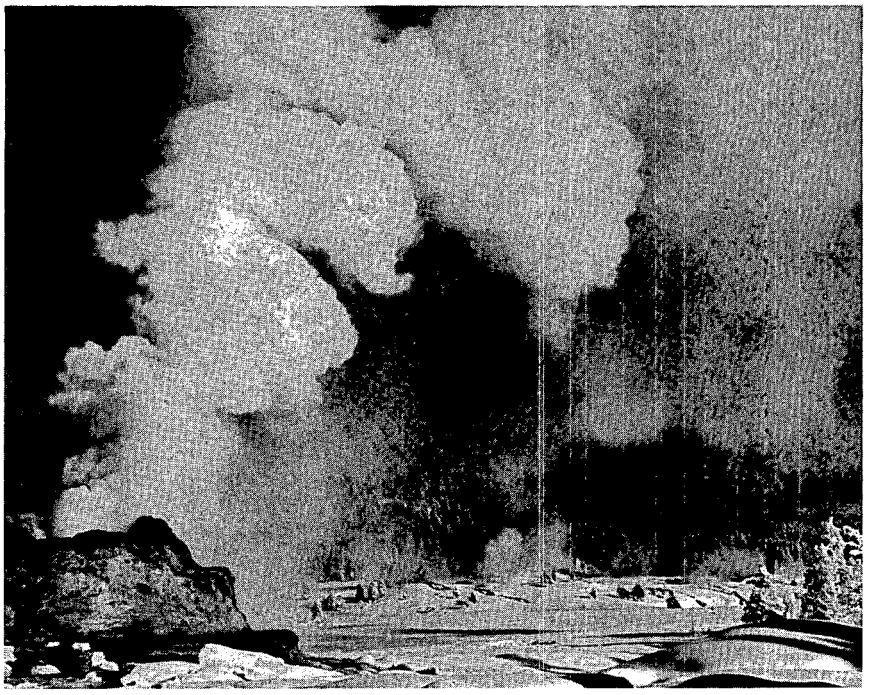
crust: the outermost, solid layer of the earth.

Geothermal power, literally "the heat of the earth," is not solar energy at all. It comes from the processes that occur in and under the earth's crust, processes dating from the original event in which both the earth and the sun came into existence.

mantle: the intermediate shell below the crust and above the core of the earth.

The breakdown of radioactive material within the earth and the pressure and friction of changes in the earth's crust and mantle produce heat. This heat may be stored in solid rock of the earth's upper layers, or in molten rock which sometimes thrusts upward into cracks and pockets in those layers.

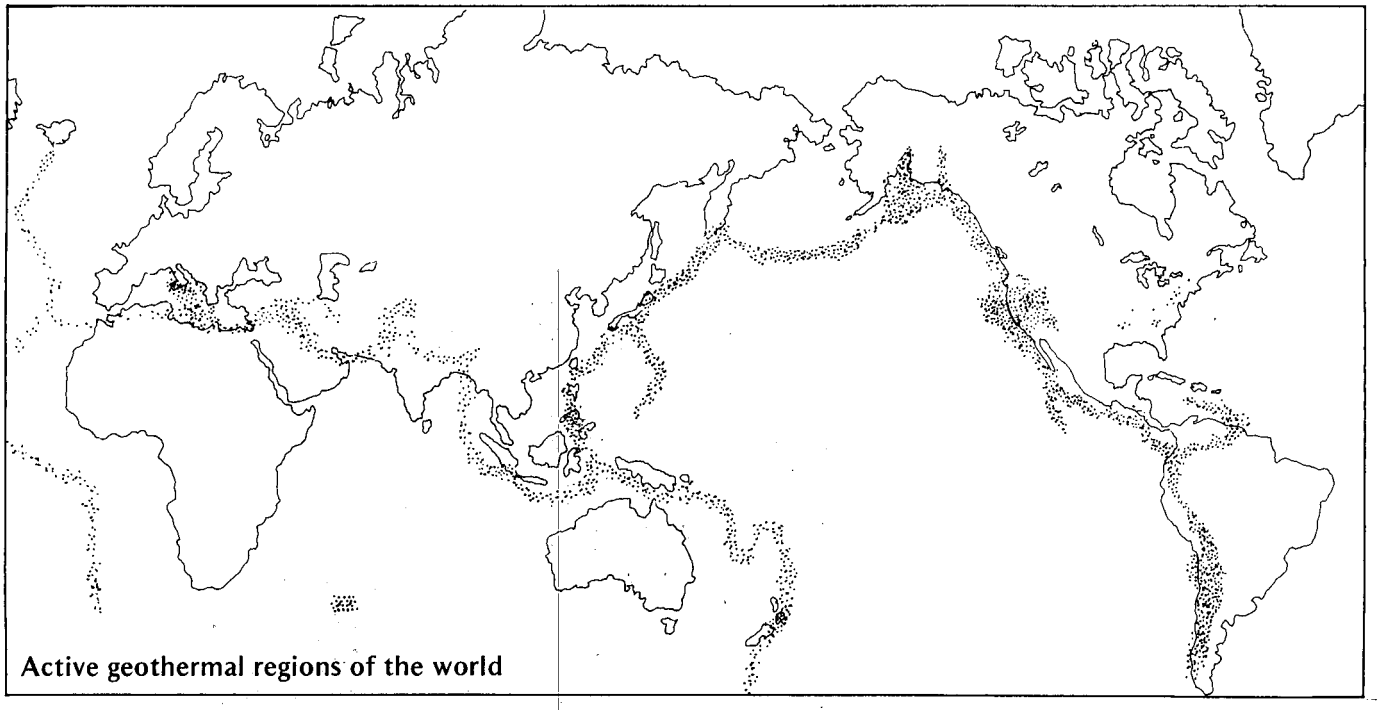
This hot or molten rock sometimes comes into contact with subsurface reservoirs of water, heating the water and producing steam and pressure. Where this pressurized steam or hot water finds an outlet we have geysers or hot springs. Most of the homes of Iceland's capital city of Reykjavik are heated by geothermal heat, and for centuries many countries have used hot springs as health resorts.



Vincent J. Schaefer

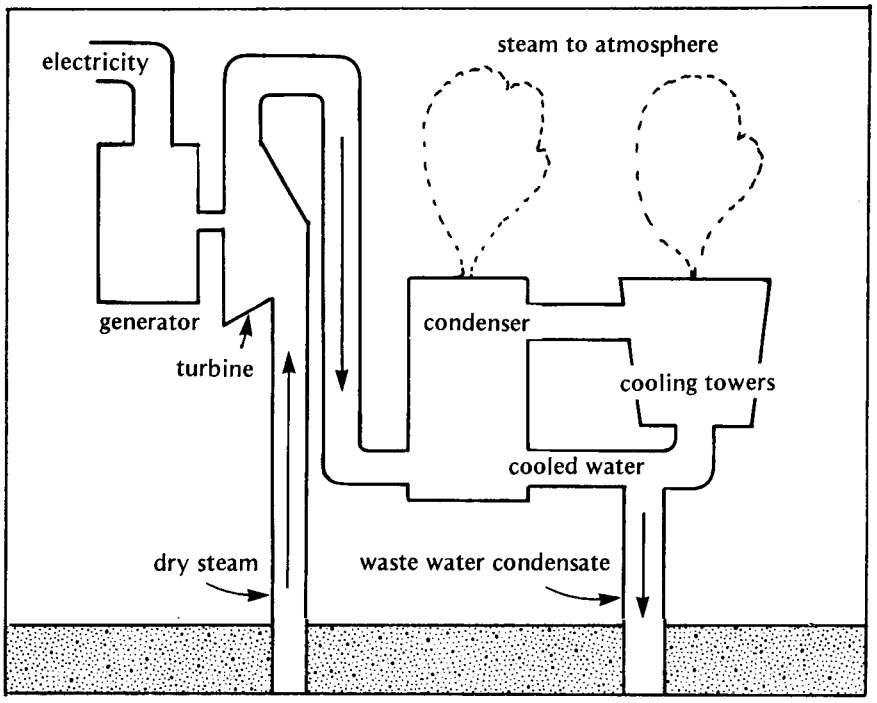
Castle Geyser at Yellowstone shows geothermal power in its natural state.

Today geothermal energy is being developed most in areas where it is most available - usually areas with hot springs and geysers or areas of known earthquake activity: the western coast of the Americas, New Zealand, and Italy for example. Although it can be used for direct heating, most interest today is focussed on the use of geothermal



Active geothermal regions of the world

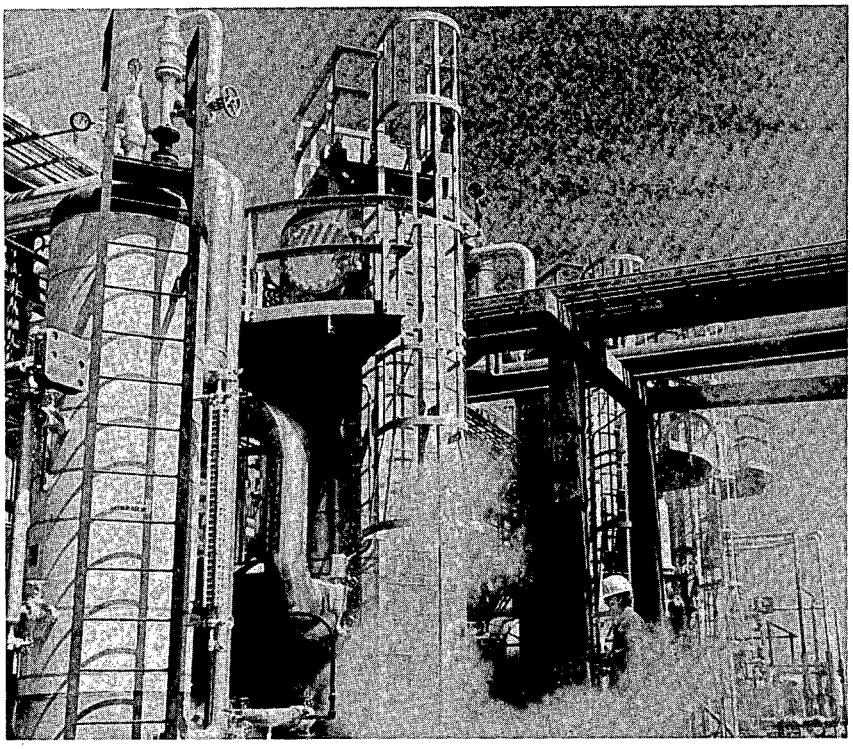
energy to generate electricity. (The Geysers field in northern California has a generating capacity of about 1000 megawatts, for example, and that capacity is being added to each year.) Where hot rock is thought to exist without contact with underground water, some projects are experimenting with piping water to the heat source and then pumping the resulting steam to the surface for use.



Dry steam geothermal system

Improvement is needed in deep, high-temperature drilling techniques, as well as in dealing with the environmental effects of geothermal development. A geothermal facility occupies a large area; pipes must be vented periodically, resulting in loud noises and sometimes foul-smelling gases.

A particular limitation of geothermal development is that it is a localized resource, and each individual site is different. However, the techniques developed for tapping oil deposits should help smooth the path to fuller use of the abundant geothermal reservoir of energy.



U.S. Department of Energy

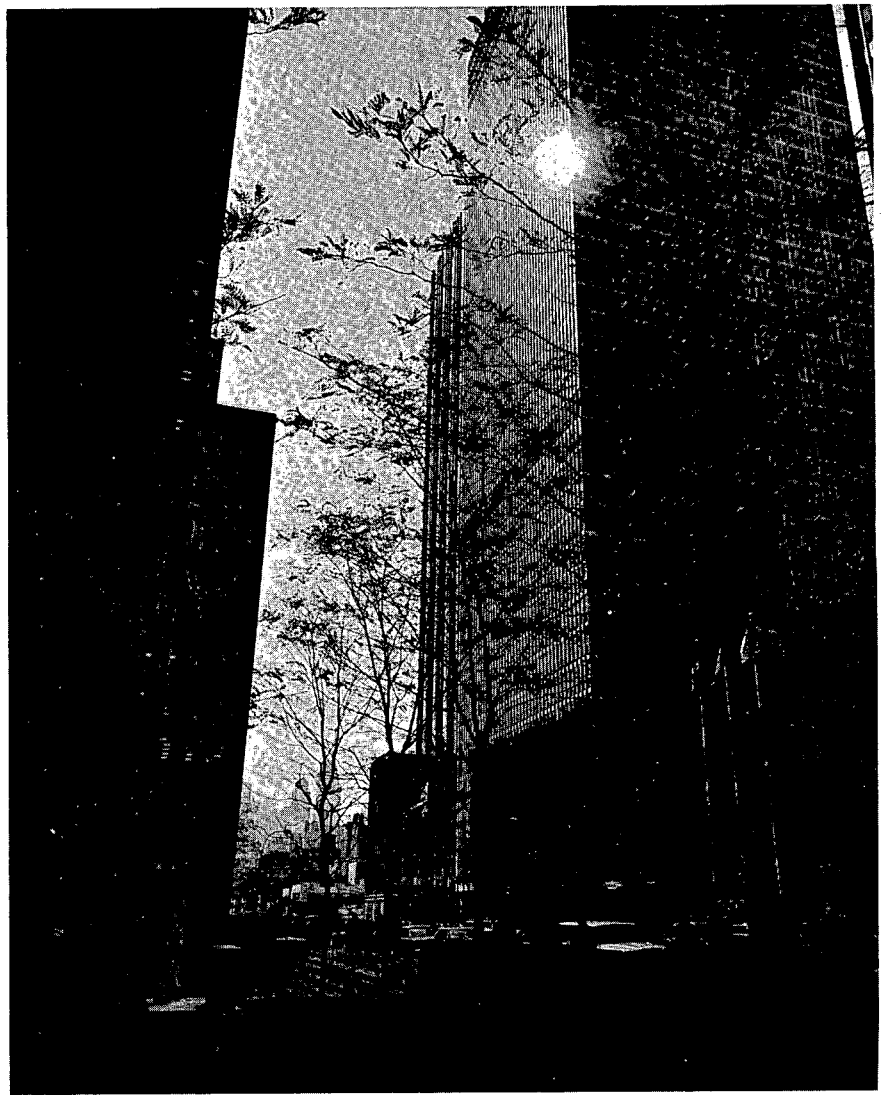
This experimental facility in California's Imperial Valley is designed to produce 10 megawatts of geothermal electricity.

Financing Alternative Energy on a Large Scale

The adoption of active and passive solar, wind systems, and conservation measures is often a personal and local choice. Though these personal choices, in combination, may profoundly affect larger patterns of energy use, they cannot force the utility companies and the government to begin large scale use of clean, renewable energy. Such change will require major rethinking, reinvestment, and redevelopment. For technologies like OTEC, tidal, and geothermal power to be adopted, it will be necessary for the pressures of economics, environment, and politics to act upon people in positions of power. As the supply of fossil fuel becomes increasingly uncertain, as the environmental effects of old energy policies become more pronounced, and as people begin to vote with greater energy consciousness, we can expect to see greater attention paid to OTEC, tidal, and geothermal power and other large-scale renewable energy alternatives.

Chapter 22

Solar Support



N.Y.S. Department of Commerce

Any society, whether a family, a community, a nation, or the world, is a complex structure. All the parts are interlocking, both supporting and supported by each other. When one piece is removed or changed or replaced, the other pieces have to be adjusted to accommodate the change.

As the various forms of solar energy assume a more important place in the world's energy supply, society will have to make appropriate adjustments. If solar energy is to help support the future of human society then that society must be prepared in turn to support solar energy.

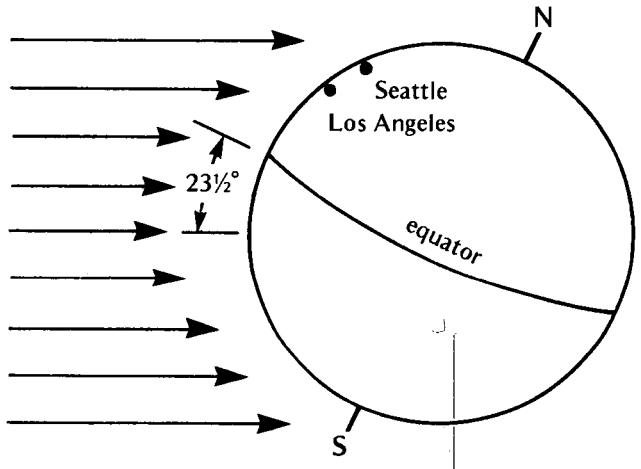
Daily the pressure and the demand for this support become more apparent. Three problem areas in particular are featured in frequent news items. It is obvious that the friction of adjustment is being felt in these areas: the legal system, the financial system, and what might best be called the "social values system."

The Sun and the Law

Legal questions about the sun revolve around the issue of the right to sunlight. As far as the United States is concerned, the issue is in its infancy. Any legal cases of note up to this point have simply established the following rule: a property owner has a right to sunlight from directly above the property, but not to sunlight that slants over neighboring property.

solar rights (solar access): the right to receive direct sunlight without interference.

For anyone who lives any distance north or south of the equator, such a rule is often worthless from a solar standpoint. Let's take the latitudes from Los Angeles to Seattle as an example. If we consider the bulk of the heating season to stretch from mid-December to mid-March, we find that the sun's highest angle anywhere in that region for that time period is 52° above the horizon. That is, 52° would be the high point for Los Angeles in mid-March. In Seattle in mid-December, on the other hand, the highest the sun would reach at midday would be 18.5° above the horizon.



Orientation of earth to sun in December

What this means is that without planning and legal protection, people who are interested in using solar energy but live in regions of any significant population density will encounter problems of access to sunlight.

Needed: Central Direction but Local Solutions

The question of sun rights today is so new that many communities are either unaware of any need, or unprepared to deal with it. Earlier laws and codes don't provide much guidance. Litigation so far has tended to approach solar

nuisance law: various laws designed to prevent one person's interference in the rights or convenience of another.

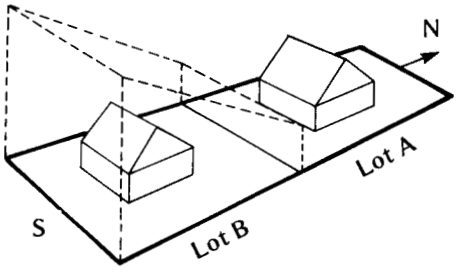
law of right by prior use: (based on water law) laws which give the first person to use a resource at a given location the right to continued use.

easement: a right to make limited use of another's land.

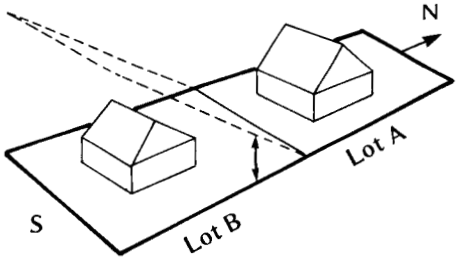
rights either from the standpoint of nuisance law or law of right by prior use. Neither is an ideal solution. More test cases are needed to help with the development of a body of precedents which can be used for guidance.

The early Roman method for protecting solar rights was the solar easement, a possible solution for today. The property owner purchases from his neighbors a passageway for sunlight that passes over their property. The neighbors agree not to obstruct the passageway. About half the states now recognize solar easements and prescribe their contents. Unfortunately, the easement is an additional expense to the solar owner.

Two possible types of solar easement
Owner of lot A has easement on lot B.



Envelope with top sloped up toward south



Plane sloping up toward south at a given angle

A better answer is for state and local governments to work out codes and zoning ordinances that encourage and protect solar energy use. Several states now have legislation that prohibits any code or ordinance from restricting solar or wind energy systems, but more positive protection is called for today.

The need now is for zoning guidelines and model regulations and master plans that could be used by local governments but tailored to their needs. Three zoning ideas that some localities have incorporated are

- "bulk plane provisions" rather than the usual uniform height limits. These allow greater height in the center of structures than on the sides, so that slanting sunlight is less likely to be blocked from neighboring property.

- "zero lot line zoning" rather than uniform setback requirements, to allow construction close to the property's north line, leaving more open space to the south.

- grouping of buildings by use or type, so that lower buildings are not apt to be overshadowed by higher ones.

The Sun and Money

While the legal system begins to address the need of solar energy systems for legal protection, the equally fundamental need for financial support is being felt.

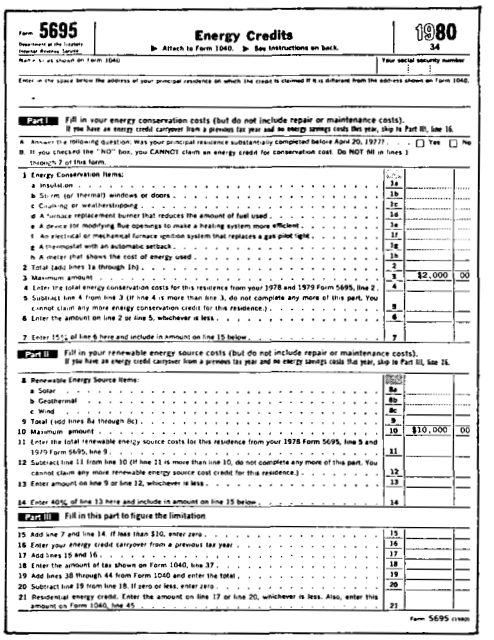
Tax Incentives

A number of states are offering some encouragement to solar development through their tax structure. Half the states offer income tax credits, deductions, or refunds for solar energy devices. About the same number give property tax deductions or exemptions, at least for a period of years. Several offer sales tax exemptions.

tax credit: an amount which may be subtracted from the total of one's tax bill.

Many of these benefits are not very substantial, however, and a number of states do not allow the taxpayers full state tax benefits if they also claim federal tax credit.

The federal income tax credit of 40% for active and wind systems has been an important incentive. However, the failure to include credit for the purchase of passive systems is a critical drawback in the federal credit.



Form 5695 — Energy Credits — 1980

▶ Attach to Form 1040. ▶ See instructions on back.

Your social security number

Part I — Fill in your energy conservation costs (but do not include repair or maintenance costs).

Part II — Fill in your renewable energy source costs (but do not include repair or maintenance costs).

Part III — Fill in this part to figure the limitation

Other Selling Points

To be widely adopted, a new technology needs a variety of incentives. Some of these are financial in the obvious sense: tax credits, government and industry research funding, investment capital.

Other incentives are also financial, but in a more subtle way. Education and information cost money and are crucial to the wide acceptance of a new idea. For example:

- Banks and lending institutions must be convinced that a "solar loan" is a good risk.

- Students of architecture and engineering need courses to prepare them for work with solar technologies.

- Utilities should be shown that by encouraging solar and conservation, they actually save money.

- High schools and technical schools have to be encouraged to train skilled installers of solar systems.

- Community groups need ideas and models for setting up cooperatives to bring down the cost of purchasing and installing solar systems.

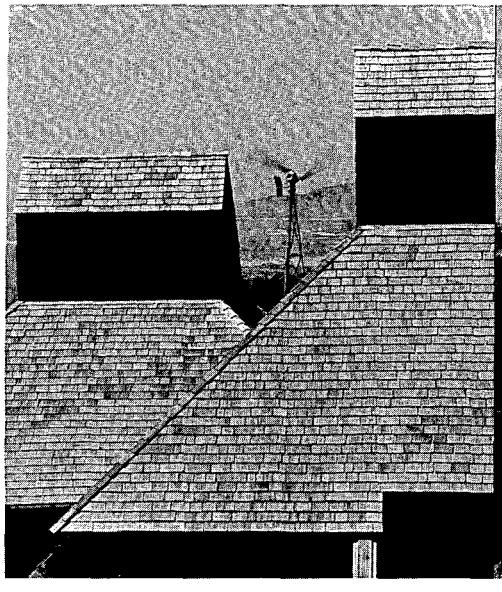
- The public must be exposed to modest, low-cost demonstrations of passive homes, active systems, wind generators, etc., that are ready for commercialization.

Financial backing is needed for these and other programs to prepare the public for the shift to solar energy.

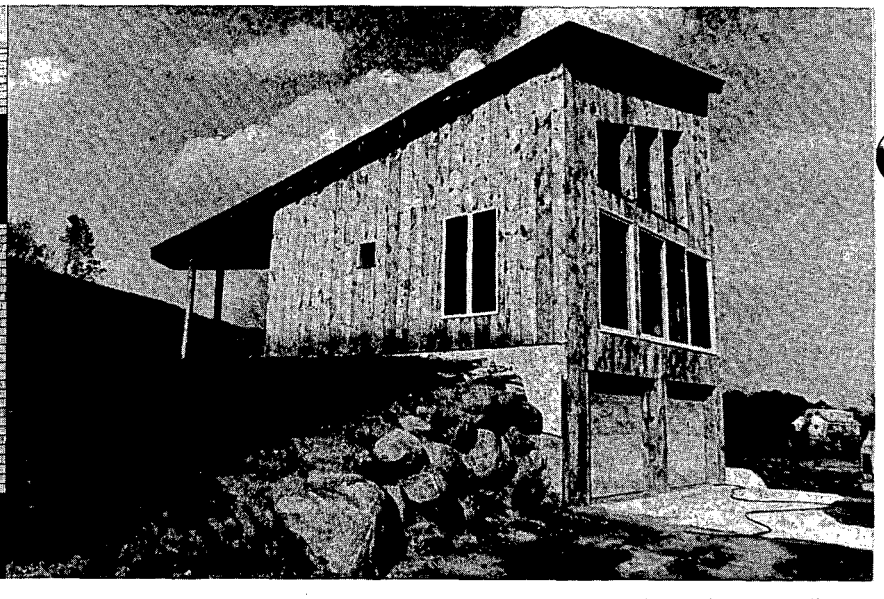
Aesthetics

The mind interprets and evaluates what the eye sees. There is nothing intrinsically beautiful about a cement swimming pool surrounded by a chain link fence, but because it suggests pleasure and affluence, we accept its appearance. Television antennas are a common sight, as are power poles, electric cable, and other utilitarian objects.

The familiar tract house, with windows on all sides, the front door facing the road, an exposed foundation, and conventional landscaping, is regarded fondly by millions because it connotes "home."



Pacific Gas and Electric



Adirondack Alternate Energy

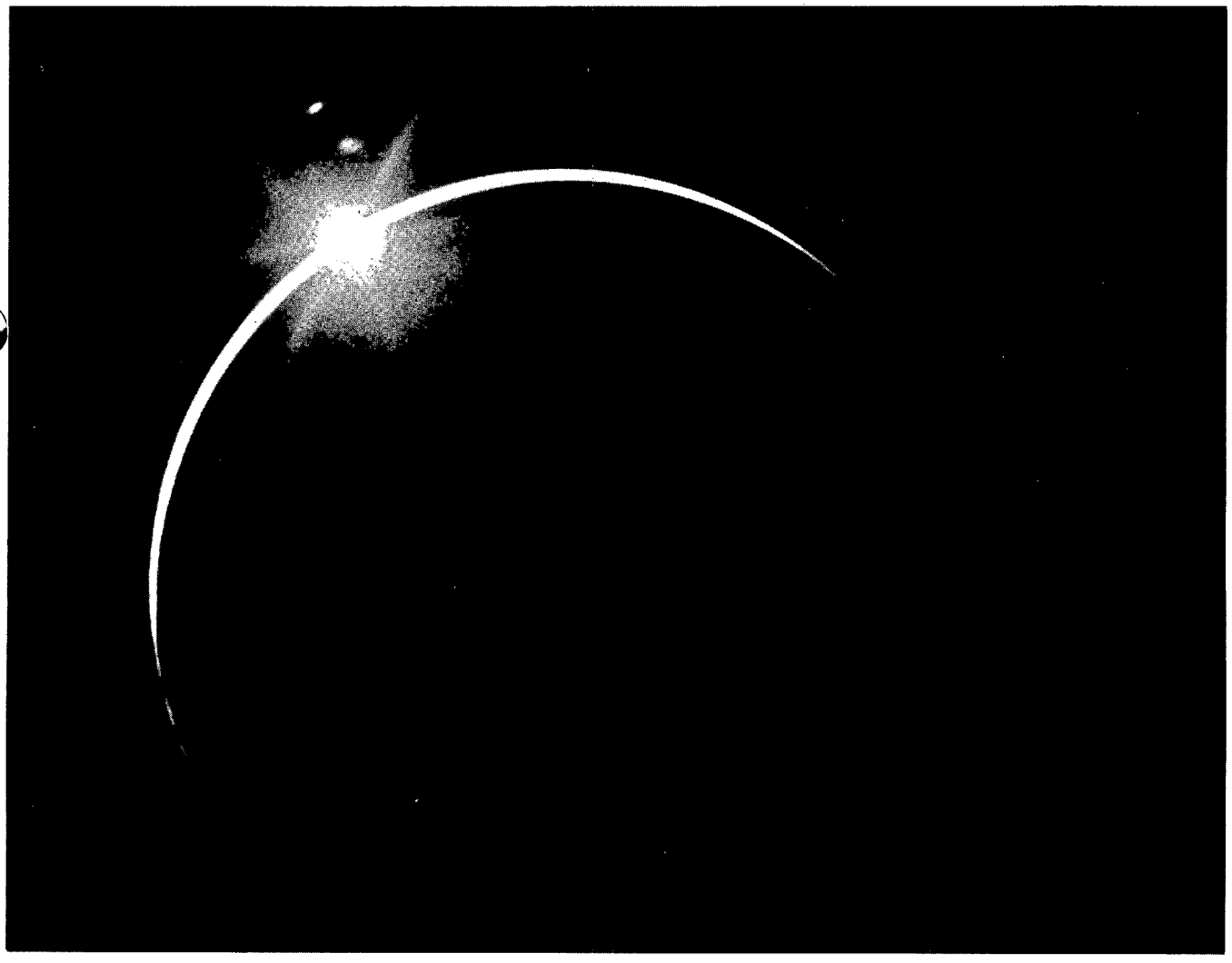
As renewable energy systems become more familiar they too will be seen as neutral or even positive objects on the landscape. We look at old windmills, waterwheels, or energy-efficient houses from early times with pleasurable nostalgia because of the way of life they remind us of. New energy systems and energy-efficient homes that harmonize with the environment and give comfort to their users will soon be viewed with equal pleasure.

Solar Values

In the process of providing the legal, financial, and informational supports for solar energy, society gradually undergoes the most important shift -- the shift in its own

consciousness. Instead of seeing solar as experimental, exotic, and eccentric, people adjust to recognizing it as practical, common, and in the mainstream. When the laws provide for solar access, the banks give solar loans, the schools teach solar architecture, stockbrokers encourage solar investment, and neighbors compare their solar systems over the back fence, the last doubts of most people will be erased.

This process is well underway. As might be expected, pockets of support and acceptance of solar energy grow around innovative people: builders, inventers, researchers, investors, teachers, planners, and entrepreneurs who share ideas and information generously. In today's energy situation, it seems inevitable that these pockets of acceptance will grow and spread until the use of solar energy is a familiar and sturdy support in the structure of our society.



National Aeronautics and Space Administration

Glossary of Renewable Energy Terms

a

absorber
a surface, usually blackened metal, which absorbs solar radiation and converts it to heat energy in a solar collector.

active solar energy system
a system which requires external mechanical power (motors, pumps, valves, etc.) to operate the system and to transfer the collected solar energy from the collector to storage or to distribute it throughout the living units. Active systems can provide space heating and cooling, domestic hot water, and/or steam for industrial use.

air exchanges
replacement of a given volume of air in a room or an entire building over a period of time. Air exchanges (AE) are sometimes expressed as whole-volume exchanges per hour or, alternatively, as cubic feet per minute (CFM). A standard, insulated new home is expected to have 1 AE/hour; a specially constructed, energy-efficient house may have only 1/2 AE/hour. Drafty, uninsulated houses typically have 3 or more AE/hour.

air pollution
the presence of contaminants (natural or man made) in the air to such a degree that the normal self-cleaning or dispersive ability of the atmosphere cannot cope with them.

alcohol fuels
primarily grain alcohol (ethanol) and wood alcohol (methanol) which have been used for decades in some European cars and in race cars. Cheap and easy availability of gasoline in the past made them uneconomical. Engine modifications will be necessary if these liquid fuels are to be put into widespread use, but small amounts of ethanol (up to 10% mixture with gasoline, as in gasohol) can be used in most cars without alterations. Alcohol fuels can be made from a variety of materials including crop surpluses, lumber wastes, municipal sewage, and garbage.

altitude
the angle formed between the horizon and the sun.

anaerobic digestion
conversion of organic material (crop residue, manure, or sewage sludge, for example) into methane by microorganisms that decompose the wastes in the absence of oxygen.

anemometer
an instrument which measures the speed of the wind.

anthracite
"hard coal", low in volatile matter, which burns with very little smoke and flame and consists almost entirely of carbon; now scarce in the U.S.

automation
the condition of controlling and operating equipment and systems automatically, and the techniques and equipment used to do so; also, the replacement of human or animal labor by machines, or of human control by mechanical or electric control.

azimuth
the angle formed between true south and the point on the horizon directly below the sun.

b

backup energy system
an energy system using conventional fuels to supply all the heating and domestic hot water during any period when the solar energy system is not operating.

barrel
a liquid volume equal to 42 gallons or 159 liters. One barrel of crude oil has about the same heat energy as 350 pounds of bituminous coal, 5.8×10^9 joules or 5.5×10^6 Btu or 1.39×10^6 kcal.

bioconversion
a general term describing the conversion of one form of energy into another by living organisms. Examples are production of wood and sugars by green plants, production of alcohols and natural gases by microorganisms acting on organic materials, and transfer of energy in food chains.

biofuels
renewable energy sources produced by or from green plants. Examples are grain alcohol, wood, methane from anaerobic digesters, all foods.

biomass
a volume or amount of plant material in any form: algae, wood, plants, crop residue, animal manure, etc.

bituminous coal
soft coal, volatile and high in carbonaceous matter, which burns with much smoke and a yellow flame. It is "younger" and of lower heat value than anthracite.

blanket insulation
cotton fiber, mineral wool, or wood fiber made into lengths of varying thicknesses.

breeder reactor
a more complex nuclear reactor than ones now in commercial use, a breeder converts non-fissionable uranium or thorium to nuclear fuel. Conventional nuclear reactors depend on fission of an uncommon form of uranium, U_{235}, which comprises less than 1% of uranium ore. To extend the use of uranium, breeder reactors may be able to change more abundant forms of uranium into fissionable elements. Higher operating risks, engineering problems, and waste disposal considerations have been factors in slow development of breeder technology.

brown coal
See lignite

Btu
British thermal unit, a unit for measuring heat; a Btu is the quantity of heat necessary to raise the temperature of one pound of water one degree Fahrenheit, about one-fourth of a kilocalorie (252 calories).

C

calorie (also: gram calorie)
a metric unit of heat energy; the amount of heat needed to raise the temperature of one gram of water one degree Celsius. It equals 0.0039 Btu. One thousand calories make one kilocalorie (kcal), sometimes called a Calorie or a food Calorie.

capital intensive
requiring heavy capital investment. The energy industry, for example, is said to be capital intensive rather than labor intensive because it employs relatively more dollars and relatively fewer people compared to some other industries.

catalytic converter
a device added to an exhaust system or chimney that converts the air pollutants carbon monoxide and hydrocarbons to carbon dioxide and water. A similar conversion also removes nitrogen oxides.

caulking
a soft, semi-solid material that can be squeezed into nonmovable joints and cracks of a building, thereby reducing the flow of air into and out of the building.

clerestory
a window located high in a wall near the eaves, used for light, solar gain, and ventilation.

coal
solid fuel formed by the decomposition of plants buried deep under the earth's surface. A group of naturally occurring, carbon and hydrogen-rich substances are called "coal". Various types are ranked by the percentage of carbon in dried samples or by the caloric value of moist ones. From least to most carbon-rich, the coal group includes peat, lignite, sub-bituminous and bituminous coals, and anthracite.

coal gasification
the conversion of coal to a gas suitable for use as a fuel; similar to natural gas; the biggest advantage is that sulfur and other pollutants in coal can be removed before it is burned.

coal liquefaction
the conversion of coal into liquid fuels similar to gasoline and kerosene.

collector
any of a wide variety of devices (flat-plate, concentrating, vacuum tube, greenhouse, etc.) which collect solar radiation and convert it to heat.

collector efficiency
the fraction of incoming radiation converted to heat and stored by the collector. If a system captures half of the incoming radiation, the system is 50% efficient.

collector tilt
the angle, measured from the horizontal, at which a solar collector is tilted to face the sun for better performance.

compost
a mixture of decomposing plant refuse, manure, etc. used for fertilizing and conditioning the soil.

concentrator
a reflector or lens designed to focus a large amount of sunlight into a small area thus increasing the intensity of the energy collected. In wind terminology, a device or structure that increases the speed of the wind.

conduction
the transfer of heat energy through a material by the motion of adjacent atoms and molecules.

conservation
making the best use of natural resources by reducing waste, improving efficiency, and slowing the rate of consumption.

convection
the transfer of heat energy from one location to another by the motion of fluids which carry the heat.

cover plate
a sheet of glass or transparent plastic that sits above the absorber in a flat plate collector. (See also: glazing.)

crude oil
liquid fuels formed over thousand of years from the fossils of animals and plants at the bottom of ancient seas; raw materials from which most refined petroleum products are made.

cut-in speed
the wind speed at which a wind machine is activated.

cut-out speed
the highest speed which a wind machine attains, above which it shuts down; designed as a safety feature to prevent structural stresses or failures. The lower the cut-out speed, the less power generated at high wind speeds. Optimum cut-in and cut-out speeds depend on machine design and wind characteristics at the specific site where the wind machine is installed.

d

damper
a device which permits, prevents, or controls the passage of air through an air outlet, inlet, or duct.

deciduous
describes trees and shrubbery that lose their leaves during the fall season of each year and produce new foliage in the spring.

declining block rate
a method of charging for electricity wherein a certain number of kilowatt hours (the first block) is sold at a relatively high rate and succeeding blocks are sold at lower and lower rates. Thus the charge for energy decreases as the amount consumed increases.

deforestation
the process of removing trees or clearing forest from an area.

degree day
a unit which describes the severeness of a particular climate, used in the heating industry as a measure of the amount of heating needed. The number of degree days for a particular day equals 65 degrees Fahrenheit minus the average outdoor temperature for that day.

diffuse radiation
indirect sunlight that is scattered from air molecules, dust, and water vapor, and casts no shadow.

direct radiation
sunlight which casts shadows, received directly from the disk of the sun with little atmospheric scattering.

direct solar gain
a type of passive solar heating system in which solar radiation passes through the south-facing living space before being stored in the thermal mass.

draindown
a type of liquid, active solar heating system which protects collectors from freezing by automatically draining when the pump is turned off.

dry steam
a type of geothermal resource which is mostly composed of water vapor without water droplets. The Geysers, a sizable commercial geothermal electric power plant near San Francisco, depends on dry steam. Wells from 4,000 - 8,000 feet deep bring up steam at 300° C.

e

earth berm
a bank of dirt that abuts a building, used to stabilize interior temperature or to deflect the wind.

ecology
the branch of biology that deals with the relationship of living things to their environment and to each other.

EER (energy efficiency ratio)
an indicator of how completely an electrical appliance converts energy at the point of use. The number stated on most appliance tags is derived by comparing heating or cooling power (output) to energy consumed (input). The higher the EER, the more efficient the appliance.

effluent
any pollutants discharged to the surrounding air, land, or water.

electrostatic precipitator
a device that removes the bulk of particulate matter from the exhaust of power plants. Charged particles are attracted to electrically charged plates and the accumulation can then be washed away.

emission standard
a rule or measurement established to regulate or control the amount of a given pollutant which may be discharged to the outdoor atmosphere from its source.

energy
the ability to do work or make things move; the application of a force through a distance. Energy exists in a variety of forms (electrical, kinetic or motion, gravitational, light, atomic, chemical, heat) and can be converted from one to another. Common units are calories, joules, Btu, and kilowatt-hours.

energy audit
the examination of a building's construction and materials, mechanical and electrical systems, energy usage patterns, and fuel history in order to identify possibilities for energy conservation.

entropy
a measure of the energy that is unavailable for use in a system, because it cannot be converted to another form; entropy therefore reflects the inefficiency of a system. The second law of thermodynamics states that the amount of entropy in the universe is constantly increasing.

environment
the sum of all external conditions and influences affecting the life, development, and ultimately the survival of an organism.

eutectic salts
a group of materials that melt at a low temperature, and absorb large quantities of heat in the process.

evaporation
the change from liquid to gas which requires extraordinary absorption of heat by the material undergoing this phase change. Liquid water, for example, absorbs 540 extra calories per gram at 100° C as it vaporizes. This heat will be released again if the water vapor condenses.

f

feedstocks
energy resources used as raw materials in the production of medicines, plastics, rubber, fertilizers, paints, and hundreds of other products, instead of as fuels.

fission
a nuclear reaction in which large atoms are split in two with the release of large amounts of energy. Heat produced by fission of a particular kind of uranium, U_{235}, is used to generate electricity in Western Europe, the U.S., and Japan.

flat-plate collector
an enclosed, glazed panel containing a dark absorbing surface that converts sunlight to heat without the aid of a reflecting surface to concentrate the rays. The collector transfers its heat to a circulating fluid.

fluidized bed
a furnace design in which gas is blown through a layer of finely crushed solids buoyed up by air. Because of close contact of the solids and gases, high rates of heat transfer and uniform temperatures can be achieved. This kind of furnace also enables removal of sulfur during combustion.

fly ash
tiny particles of solid ash in the smoke of burning fuels such as coal.

foam insulation
styrofoam, rigid foam boards, or liquid foam, used as insulation.

force
the action on a body which tends to change its relative condition as to rest or motion.

fossil fuels
coal, petroleum, and natural gas; this term applies to any fuels formed from the fossil remains of organic materials (plants and animals) that have been buried for millions of years. The ultimate source of energy for those plants and animals was the sun.

fusion (nuclear)
a nuclear reaction involving combinations of small atomic nuclei into larger ones with a tremendous release of energy. Experimental fusion reactors are being developed in Europe and the U.S. The fuel for fusion is deuterium, a form of hydrogen which occurs naturally in sea water in a ratio of one atom to 6,500 atoms of normal hydrogen. Deuterium fuel is abundant, but technical and economic feasibility of fusion processes as the bases for electrical power is problematic.

g

gasohol
a fuel mixture composed of 90% unleaded gasoline and 10% ethanol (ethyl or grain alcohol).

gasoline
a petroleum product consisting primarily of light hydrocarbons. Some natural gasoline is present in crude oil, but most gasoline is formed by refining crude oil.

generating capacity
the top capacity of a power plant to generate electricity. Usually measured in megawatts.

generator
a device that converts heat or mechanical energy into electrical energy.

geothermal energy
heat trapped in the interior of the earth is called geothermal energy. Boreholes into the crust show an average temperature increase of 1° C for every 30 meters of depth, or about 100° F per mile. Geothermal heat is believed to come from the decay of radioactive materials deep in the earth as well as from friction of rock movements, tidal forces, and perhaps other sources. This heat keeps great quantities of buried rock molten and hot. Some of this energy escapes at the surface as hot water. Geothermal energy is available in four forms: dry steam, wet steam, hot rocks, and hot water.

Glauber's salts
sodium sulfate decahydrate, a eutectic salt that melts at 90 degrees Fahrenheit (32° C) and absorbs about 104 Btu per pound (12 kilocalories per kilogram) as it does so; fairly inexpensive, it is used for storing solar heat.

glazing
the transparent or translucent cover of a solar collector (also: cover plate), or that material which forms a window or skylight. In solar applications, glass or reinforced polyester is usually used as a glazing.

greenhouse effect
a phenomenon which converts solar radiation to heat. Sunlight penetrates glazing quite easily but, when absorbed by objects behind the glazing, is reradiated as heat which does not penetrate the glazing as easily. Heat is thereby trapped and can be used. Also: the warming effect of carbon dioxide and water in the atmosphere acting as a "lid" to slow the escape of heat from the earth's surface. Molecules of water and carbon dioxide absorb and reradiate back to earth much of the heat radiated from it.

h

heat
energy that flows between a system and its surroundings because of a temperature difference between them. Heat results from the motion of molecules of matter. Also, the word heat is often used to refer to the energy contained in a sample of matter (for example, kilocalories per unit of food).

heat capacity (specific heat)
the quantity of heat required to raise the temperature of a given volume of material by one degree in a given system of measurement.

heat exchanger
a device specifically designed to transfer heat between two physically separated fluids.

heat pump
a device that transfers heat from a colder region to a warmer one (or vice versa) by the expenditure of mechanical or electrical energy. The heat pump operates by alternately evaporating and condensing a refrigerant, or heat transferring fluid, in a closed cycle. It differs from a typical refrigeration unit in that the heat pump can reverse its cycle to provide heat instead of removing it. Heat pumps are both heaters and air-conditioners and, compared to electric resistance elements often used in all-electric homes, they are more efficient.

heat sink
a medium (gas, liquid, or solid) capable of accepting and storing heat.

heliostat
an instrument consisting of a mirror mounted on an axis moved by clockwork; used to reflect the sun's rays into a solar collector or furnace.

horizontal shaft wind turbine
a wind machine on which the shaft that the rotors are attached to is parallel to the earth.

hybrid solar energy system
a system that uses both active and passive methods to operate.

hydroelectric plant
an electric power plant in which the energy of falling water is converted into electrical energy by a turbine generator.

i

indirect solar gain
a type of passive solar heating system in which the storage is placed between the collecting and the distributing surfaces (example: Trombe wall, water wall, or roof pond).

infiltration
the uncontrolled movement of outdoor air into a building through cracks around windows and doors, and in walls, roofs and floors. (See also: air exchanges.)

infrared radiation
the invisible rays just beyond the red of the visible spectrum; their wavelengths are longer than those of the spectrum colors and they have a penetrating heating effect.

insolation
the energy received by earth from the sun, a contraction of the three words: incoming solar radiation. The total daily insolation is the equivalent of about 4.2 quadrillion kilowatt hours. Local insolation depends on the position of the earth in its orbit, the thickness and transparency of the atmosphere, the inclination of the intercepting surface to the sun's rays, and the solar constant. Weather bureaus now keep insolation data or "sunshine statistics".

insulation
material with high resistance (R-value) to heat flow. Some commonly used materials for home insulation are fiberglass, cellulose, rock wool, and styrofoam.

internal combustion engine
an engine which uses fuel burned within the engine itself to produce heat or pressure to do work. Examples are the gasoline piston engine and the diesel engine.

inverted block rate
a method of selling electricity wherein a first "block" of kilowatt hours is offered at a low cost and prices increase with increased consumption.

isolated solar gain
a type of passive solar heating system in which heat is collected in one area (sunspace, attic collector) and used in another (living spaces).

j

joule
a metric unit of work, mechanical energy, and heat; approximately equal to 0.74 ft-lbs or 0.00095 Btu or 0.24 calories. It is defined as the energy expended in one second by an electric current of one ampere with a resistance of one ohm.

k

kilowatt
a measure of power, usually electrical power or heat flow; equal to 1,000 watts or 3,413 Btu per hour.

kilowatt-hour
the amount of energy equivalent to one kilowatt of power being used for one hour; equals 3,413 Btu, or about 860 kcal.

langley
a unit of solar energy, its radiation intensity is equivalent to 1.0 calorie/cm^2. It can be used as a power unit when flow over time is expressed as langleys/min or langleys/hr or langleys/day. One langley/min = 221.2 Btu/hour/ft^2. One langley/min also = 697.3 watts/m^2 or 16.74 kWh.

latent heat
the amount of heat in calories or Btu absorbed when a material changes its state from a solid to a liquid or from a liquid to a gas. Latent heat is recovered by freezing a liquid or by condensing a gas.

latent heat storage
use of a heat-absorbing material's phase change behavior to design a compact thermal storage system. Unusual amounts of heat are absorbed by some solids at their melting points without causing their temperature to change. This hidden or "latent" heat is then stored in liquids until they resolidify. An example is ice, which absorbs 80 additional calories per gram after it has been warmed to 0° C and before it melts. This heat is released again only when water refreezes. Certain hydrated salts with low melting points (eutectic salts) and paraffins melt and store latent heat in the 32° C - 45° C range (90° - 113° F) easily attainable by flat-plate collectors even on cloudy days. This gives them potential for domestic heat storage. Ponds and blocks of ice are also being used for latent heat storage in some experimental heating and cooling systems.

life cycle costs
the total costs of an item including initial purchase price as well as cost of operation, maintenance, etc. over the life of the item.

lignite
a dull brown to black solid, lignite is a soft fuel in the coal group. More concentrated than peat (from which it evolves after burial beneath clay and sand), lignite has more moisture and trapped gases, a high ash content, and a woody texture compared to other forms of coal. Ninety percent of the world's reserves of lignite lie in Australia, the U.S., and the U.S.S.R.

loose insulation
small pieces of insulation which are blown into place.

m

mechanization
production by machine; also, the substitution of machinery for human or animal labor.

megawatt
a unit of power equal to 1,000 kilowatts or one million watts.

methane gas
a colorless, flammable, gaseous hydrocarbon, emitted by marshes and by dumps undergoing decomposition; can also be manufactured from crude petroleum or other organic materials.

n

natural gas
a mixture of gaseous hydrocarbons occurring naturally in certain rocks. There are several kinds of gas trapped in porous rocks underground. One of these "natural gases" is methane, used as a commercial fuel. Petroleum deposits always include some methane, but natural gas deposits are not always accompanied by petroleum. Natural gas is commonly sold to individuals in hundreds of cubic feet (CCF), the unit appearing on household utility bills. One CCF of commercial methane has about 25,000 kilocalories, the equivalent of 8 pounds of coal or 0.7 gallons of crude oil. (See also: methane.)

nonrenewable resources
energy resources that are not being replaced during the time span of human history. Examples are coal, oil, natural gas, and uranium.

nuclear energy
energy from radioactive decay or from fission or fusion reactions. In a controlled situation it can be used to produce electricity.

nuclear power plant
a generating station where heat for creating steam comes from nuclear fission instead of from combustion of fossil fuels.

nuclear reactor
a device in which a fission chain reaction can be initiated, maintained, and controlled.

o

ocean-thermal energy conversion (OTEC)
an energy technology in which the temperature difference (between cold deep water and the warm surface water 2,000 feet above it) in tropical oceans is used to generate electricity.

off-peak power
power generated during a period of low demand.

oil shale
a sedimentary rock containing solid organic matter (kerogen) that yields substantial amounts of oil when heated to high temperatures.

overhang
a solid horizontal or angled projection on the exterior of a building placed (ideally) so that it shades southern windows in summer only. An overhang may be fixed or movable, part of the original construction or a retrofit. Several designs are possible. An upward-tilted overhang can also serve as a reflector in winter.

p

particulate
a particle of solid or liquid matter (soot, dust, aerosols, fumes and mist).

passive solar energy system
an assembly of natural and architectural components which converts solar energy into usable or storable thermal energy (heat) without mechanical power. Current passive solar energy systems often include fans, however.

payback period
the time needed to recover an investment.

peak load
the maximum instantaneous demand for electrical power which determines the generating capacity required by a public utility.

peat
accumulated plant remains that decayed in a swamp, becoming a loosely packed mass of carbon-rich materials. It is usually brown, porous, and fibrous; has a high water content; and leaves much ash when burned. Nevertheless it is a valuable fuel. The U.S.S.R. has generated electricity from peat since 1914 and now has many peat-fueled power stations.

petrochemicals
chemicals removed from crude oil at the refinery and used to make a wide range of products such as plastics, synthetic fibers, detergents, and drugs.

petroleum
an oily, flammable liquid that may vary from almost colorless to black and that occurs in many places in the upper strata of the earth. It is a complex mixture of hydrocarbons and is the raw material for many products including gasoline, kerosene, lubricants, and waxes.

phase change
the process involved when a material changes from a solid to a liquid or from a liquid to a gas, each phase change requiring absorption of energy with no temperature change; or when the material changes from a gas to a liquid or a liquid to a solid, each phase change requiring a loss of energy with no temperature change.

photosynthesis
green plants' process of using solar energy to convert simple molecules into complex ones with high potential energy. Carbon dioxide and water are combined, in the presence of sunlight and chlorophyll, into carbohydrates such as sugars, starches, oils and cellulose.

photovoltaic cell
a device which converts solar energy directly into electricity. Sunlight striking certain materials (silicon is most common) causes the release of electrons. The migration of these released electrons produces an electrical current. The conversion process is called the photovoltaic effect.

pollutant
an impurity or contaminant emitted to the ambient air. It may be a solid (particulate matter), liquid (mist), or gas (such as carbon monoxide).

power
the rate at which work is performed. It is measured as units of energy per unit of time, for example: calories per second, watts (joules per second), or horsepower (foot-pounds per second).

pumped storage
a method whereby excess electricity produced during periods of low demand is used to pump water up to a reservoir. When demand is high, the water is released to operate a hydroelectric generator. Pumped energy storage only returns about 66% of the electrical energy put into it, but costs less than the cost of constructing the equivalent generating capacity.

pyranometer
an instrument for measuring the intensity of both direct and diffuse solar radiation.

pyrheliometer
an instrument that measures the intensity of the direct radiation from the sun; the diffuse component is not measured.

pyrolysis
heating in the absence of oxygen, preventing total combustion and causing chemical decomposition of the resource material. For example, pyrolysis of coal produces natural gas, synthetic crude oil, and char.

q

Q
a thousand quads; a quintillion Btu (10^{18}Btu).

quad
a gigantic energy unit (often used to state how much energy entire countries buy each year). It represents a quadrillion Btu or the amount of heat energy in 172 million barrels of oil. U.S. citizens used more than 78 quads of commercially-supplied energy in 1979.

r

radiation
the method by which heat is transferred through open space. About 60% of the heat transferred to a room from a wood stove is by radiation. Sunlight travels to us by radiation through space at "the speed of light", 299,728 kilometers per second.

rated output
the maximum output generated by a wind machine.

rated wind speed
the speed at which a wind machine produces its maximum output.

reclamation
the process of replacing the soil, clay, and rocks removed earlier to expose coal or oil shale for strip mining; compacting and contouring the site; and replanting it to restore its appearance and reduce erosion and drainage of waste materials. (See strip mining.)

renewable resources
materials that are recycled by natural processes within a relatively brief span of time (a human lifetime). Fresh water, wind, sunshine, and trees are some examples of resources that replace or recycle themselves within human time frames.

retrofit
to modify an existing building by adding a solar heating or cooling system or insulation to improve its energy efficiency.

rotor
a rotating blade or other surface moved by the wind.

R-value
the resistance to heat flow, reciprocal of U-value. The higher the R-value, the greater the insulating efficiency of the material. R-values are commonly stated per inch of building material. R-values are additive--thicker material or a combination of materials means increased resistance to heat flow. Some typical R-values per inch of material are 6.25 for polyurethane foam, 3.17 for fiberglass batts, 1.25 for fir and pine wood, 0.18 for plaster, and 0.08 for concrete.

S

scrubber
a device that uses a liquid spray to remove aerosol and gaseous pollutants from an airstream. The gases are removed either by absorption or chemical reaction. Solid and liquid particulates are removed through contact with the spray.

selective surface
a special coating sometimes applied to the absorber plate of a solar collector. The selective surface absorbs most of the incoming solar energy and reradiates very little of it.

sensible heat
heat which, when gained or lost, results in a change in temperature.

shroud
a structure used to concentrate or deflect the wind.

smog
a term coined, originally, to characterize any objectionable, visible combination of smoke and fog; in current usage, not always visible or involving fog. Two principal types are

London smog -- occurs at night or on cold, foggy days and is characterized by high content of smoke particles, sulfur compounds and fly ash, and

photochemical (or Los Angeles) smog -- prevalent in the daytime around sunny, poorly ventilated, heavily motorized urban areas.

solar access or solar rights
the right to receive direct sunlight without interference. The protection of solar access is a legal issue.

solar cell
see photovoltaic cell.

solar constant
the average amount of solar radiation reaching the earth's atmosphere per minute, 1,350 watts per square meter or 429 Btu per square foot per hour.

solar energy
the electromagnetic radiation emitted by the sun. The earth receives about 4,200 x 10^{15} kilowatt-hours of solar radiation per day.

solar furnace
a device using mirror reflectors or lenses to produce very high temperatures at a focal point or "hot spot." Small backyard furnaces generate temperatures as high as 1,100 degrees Celsius; the largest solar furnace in the world reaches 3,100 degrees Celsius.

solar greenhouse
a sunspace containing thermal mass and used to grow plants.

solar pond
a shallow pond of deliberately layered water, concentrated salt water on the bottom and fresh water on top, used to collect solar heat. The dense salt water resists rising, even when heated by the sun. When it gets hot (about 80° C), it is pumped into coils of a heat exchanger to vaporize a volatile liquid that, in turn, is directed against blades of a turbine to produce electric current. Israel has an active solar pond program. Southern California Edison plans a demonstration facility at the Salton Sea in Imperial Valley. Some home builders are also using solar salt ponds for energy storage in conjunction with heat pumps for year-round space heating and cooling.

stagnation
a high temperature condition occurring in a solar collector when the sun is shining and no fluid is flowing through the collector; temperatures range from 250 degrees Fahrenheit to 400 degrees Fahrenheit (120° - 205° C), depending on collector design. Any condition under which a collector is losing as much heat as it gains.

steam engine
an engine which uses steam to drive a piston to produce mechanical power.

Stirling engine
an external combustion engine in which air (or hydrogen in the newer versions) is alternately heated and cooled to drive the piston up and down. It is claimed to be nonpolluting and more efficient than the internal combustion engine.

storage
the device or medium that absorbs collected heat and stores it for later use.

strip mining
mining for coal or useful ores by removing the soil and rock found above them, rather than by tunneling underground.

sunspace
a living space enclosed by glazing; a sunroom or greenhouse.

sun tempering
technique for taking advantage of solar radiation for winter heating but controlling solar gain for summer cooling; does not assume distribution or storage.

synthetic fuel
liquid, solid, or gaseous fuels produced from carbon-rich materials by human technology. Examples are coal gasification, coal liquefaction, oil shale extraction, and trash-to-energy conversions.

t

tar sand
a sandy geological deposit in which low grade, heavy oil is found, binding the sand together; can be mined and refined to produce fuel.

technological
relating to the application of scientific knowledge to industrial, commercial and other practical processes.

temperature
a measure of the energy of motion of the atoms and molecules of a substance. Thermometers and thermistors are used to measure an object's temperature. Temperature is not the same as heat. The tip of a burning match has a high temperature, but the object as a whole might contain very little heat due to its size.

therm
a unit used in heating calculations, equal to 100,000 Btu, the energy of approximately 100 cubic feet of natural gas.

thermal mass
mass used to store heat energy, usually collected solar energy. Insulated rock bins, sand beds, and containers filled with water or eutectic salts have been used successfully as thermal masses.

thermal pollution
degradation of water quality by the introduction of a heated effluent. Primarily a result of the discharge of cooling waters from industrial processes, particularly from electrical power generation.

thermal storage
a system which uses brick, rocks, concrete, water walls, salt ponds, eutectic salts, or other materials to store heat energy. Thermal storage is especially desirable for solar-heated homes.

thermodynamics
the relationship between the various forms of energy, and the transformations from one form to another.

thermonuclear reaction
a fusion reaction which is initiated by intense heat. The sun's energy production and hydrogen bombs are examples of thermonuclear reactions.

thermosiphoning
heat transfer in a fluid (air, liquid) by means of currents resulting from the natural fall of heavier, cooler fluid and rise of lighter, warmer fluid.

thermostat
a temperature-sensitive device which turns heating and cooling equipment on and off at set temperatures.

tracking
for a solar collector, the process whereby the panel follows the sun.

transfer medium
the fluid that carries heat from the solar collector to storage or from storage to the living areas.

Trombe wall
masonry, typically 8 to 16 inches thick, blackened and exposed to the sun behind glazing; a passive solar heating system in which a masonry wall collects, stores, and distributes heat.

turbine
a motor, the shaft of which is rotated by a stream of water, steam, air, or other fluid from a nozzle. The fluid is forced against the blades of a wheel.

U

U-value (coefficient of heat transmission)
the rate of heat transmission measured per degree of temperature difference per hour, through a square foot of wall or other building surface; the reciprocal of R-value.

V

vapor barrier
a waterproof liner used to prevent passage of moisture through the building structure. Vapor barriers in walls and ceilings should be located on the heated surface of the building.

vertical shaft wind turbine
a wind machine on which the shaft supporting the rotors is perpendicular to the earth.

W

wastes, radioactive
by-products of producing power by splitting atoms in a nuclear power plant; some of these materials are highly radioactive and remain radioactive for long periods of time.

water wheel
a wheel turned by flowing water to drive machinery.

watt
a unit of measure for electrical power equal to the transfer of one joule of energy per second. The watt is the unit of power most often associated with electricity and is determined by multiplying required volts by required amperes. One horsepower = 746 watts.

weatherstripping
material which reduces the rate of air infiltration around doors and windows. It is applied to the frames to form a seal with the moving parts when they are closed.

WECS (wind energy conversion system)
a system which converts mechanical energy from the wind to electricity, heat, or fuel which is used directly or stored.

windbreak
a dense row of trees, or a fence or other barrier that interrupts and changes the local path of the wind.

wind charger
a wind machine equipped with a generator to produce electric power.

wind chill factor
the relationship between cooling conditions at various temperatures and wind speeds, as measured by the freezing rate of water sealed in a plastic container and exposed to winds of various speeds at a given temperature. The enclosed water models human flesh. The experiments were devised by Antarctic scientists who wanted to know how fast their faces would freeze under certain conditions. All materials and systems lose heat faster when wind is blowing, so this factor should be considered, in addition to degree days, in estimating heating requirements of buildings and machinery in windy regions.

windmill
a machine run on energy generated by wind blowing against blades or slats.

window treatments
applications to the interior side of windows (blinds, shades, shutters, draperies).

wind turbine generator
see WECS.

work
energy transferred from one object to another, that is, a force acting against resistance to produce motion in a body; measured by the product of the force acting and the distance moved through, against the resistance.

X Y Z

zoned heating
the control of temperature in a room, or group of rooms, independently of others.

References

Chapter 1

Apollo-Soyuz Pamphlet No. 3: Sun, Stars, In Between, Lou Williams Page and Thornton Page.
(National Aeronautics and Space Administration, Washington, DC, 1977.)

"The Energy of the Sun", Edward Ricciuti.
(The Curious Naturalist, January 1975.)

Exploration of the Solar System.
(National Aeronautics and Space Administration, reprinted with permission from American Institute of Aeronautics and Astronautics, New York, NY, 1974.)

"The Flaming God", Isaac Asimov.
(Saturday Review, October 30, 1976.)

A New Sun: The Solar Results from Skylab, John A. Eddy.
(National Aeronautics and Space Administration, Washington, DC, 1979.)

Planets, Stars, and Galaxies, Revised edition, Stuart J. Inglis.
(John Wiley & Sons, Inc., New York, NY, 1967.)

"Star of Stars", Albert Rosenfeld.
(Saturday Review, October 30, 1976.)

"The Star That Controls Our Lives", Lillian Borgeson.
(International Wildlife, July/August 1980.)

"The Sun", Herbert Friedman.
(National Geographic, November, 1965.)

"The Sun's Back Pages", Kendrick Frazier.
(Mosaic, Vol. 12, No. 3, May/June 1981.)

Chapter 2

Energy: An Introduction to Physics, Robert H. Romer.
(W. H. Freeman and Company, San Francisco, CA, 1976.)

Nuclear Survival: A Resource Handbook, The University of the State of New York.
(New York State Education Department, Albany, NY, 1961.)

Sourcebook on Atomic Energy, Second edition, Samuel Glasstone.
(D. Van Nostrand Company, Inc., Princeton, NJ, 1958.)

Chapter 3

Solar Energy for Man, B.J. Brinkworth.
(John Wiley & Sons, New York, NY, 1972.)

Chapter 4

Living in the Environment: Concepts, Problems, and Alternatives, Third Edition, G. Tyler Miller, Jr.
(Wadsworth Publishing Company, Inc., Belmont, CA, 1982.)

People's Solar Sourcebook, Solar Usage Now, Inc.
(Solar Usage Now, Inc., Bascom, OH, 1980.)

Solar Concepts: a Background Text, Jonathan W. Gorham.
Solar Concepts: a Teacher's Guide, Jonathan W. Gorham.
(Maine Audubon Society, Falmouth, ME, 1979.)

Chapter 5

A Field Guide to the Atmosphere, Vincent J. Schaefer and John A. Day.
(Houghton Mifflin Company, Boston, MA, 1981.)

A New Sun: The Solar Results from Skylab, John A. Eddy.
(National Aeronautics and Space Administration, Washington, DC, 1979.)

Chapter 6

Living in the Environment: Concepts, Problems, and Alternatives, Third edition, G. Tyler Miller, Jr.
(Wadsworth Publishing Company, Inc., Belmont, CA, 1982.)

Chapter 7

Earth Science: The World We Live In, Samuel N. Namowitz.
(D. Van Nostrand Company, Inc., Princeton, NJ, 1953.)

Living in the Environment: Concepts, Problems, and Alternatives, Third edition, G. Tyler Miller, Jr.
(Wadsworth Publishing Company, Inc., Belmont, CA, 1982.)

Chapter 8

"How to Site a House", Terry Hallock.
(Yankee, May 1980.)

The Solar Energy Notebook, William H. Rankins, III and David A. Wilson.
(Lorien House, Black Mountain, NC, 1976.)

"Solar Energy Use and Litigation in Ancient Times", Borimir Jordan and John Perlin.
(Solar Law Reporter, September/October 1979.)

"The Sun: Who Owns It?", Earl A. Talbot and Dawn Walter.
(The Appraisal Journal, October 1979.)

Chapter 9

Applied Solar Energy: An Introduction, Aden B. Meinel and Marjorie P. Meinel.
(Addison-Wesley Publishing Company, Reading, MA, 1976.)

Climatic Atlas of the United States.
(U.S. Department of Commerce, National Climatic Center, Asheville, NC, 1979.)

Direct Use of the Sun's Energy, Farrington Daniels.
(Yale University Press, New Haven, CT, 1964.)

Input Data for Solar Systems.
(U.S. Department of Commerce, National Climatic Center, Asheville, NC.)

Local Climatological Data Reports.
(U.S. Department of Commerce, National Climatic Center, Asheville, NC.)

The Passive Solar Energy Book, Edward Mazria.
(Rodale Press, Inc., Emmaus, PA, 1979.)

Chapter 10

"Behold, My Brothers".
(The Curious Naturalist, April 1975.)

Energy for Survival, Wilson Clark.
(Anchor Press/Doubleday, Garden City, NY, 1974.)

Energy Future: Report of the Energy Project at the Harvard Business School, edited by Robert Stobaugh and Daniel Yergin.
(Random House, New York, NY, 1979.)

"Energy, Technology, and the Story of Man", Melvin Kranzberg.
(The Science Teacher, March 1972.)

Rays of Hope, Denis Hayes.
(W.W. Norton & Company, Inc., New York, NY, 1977.)

Soft Energy Paths, Amory Lovins.
(Harper & Row Publishers, Inc., New York, NY, 1977.)

"The Transition to a Post-Petroleum World", Denis Hayes.
(Journal of Home Economics, May 1978.)

Chapter 11

"A City Changes Its Energy Future", Katherine Alvord and Michael R. Eaton.
(Sierra, May/June 1979.)

Design for a Limited Planet, Norma Skurka and Jon Naar.
(Ballantine Books, New York, NY, 1976.)

"A Home-Built Solar Heater", Roger N. Perry Jr.
(The Family Handyman, September 1980.)

"How to Site a House", Terry Hallock.
(Yankee, May 1980.)

"The Insolarium: One Way to Solarize a Mobile", Frederic S. Langa.
(Rodale's New Shelter, September 1980.)

"Life in the Greenhouse", Miriam Klein.
(Solar Age, June 1980.)

"Microclimate: Don't Fight the Site", Benjamin Rogers.
(The Solar Age Resource Book, SolarVision, Inc., 1979.)

"The 'Other' Energy Crisis".
(Rodale's New Shelter, July/August 1980.)

The Passive Solar Energy Book, Edward Mazria.
(Rodale Press, Inc., Emmaus, PA, 1979.)

"A Problem with Passive", George O.G. Lof.
(Solar Age, September 1978.)

"Shelterbelts", Fred J. Nisbet.
(Blair & Ketchum's Country Journal, September 1977.)

"Solar Energy Use and Litigation in Ancient Times", Borimir Jordan and John Perlin.
(Solar Law Reporter, September/October 1979.)

"Solar Homes: The Shape of Things to Come?", Patricia A. Kovacs and William W. Rasor.
(The Science Teacher, April 1978.)

Sunspots, Steve Baer.
(Cloudburst Press, Mayne Island & Seattle, WA, 1979.)

"Tinkering with Sunshine", Tracy Kidder.
(The Atlantic Monthly, October 1977.)

"Virginia Is for Louvers", Frederic S. Langa.
(Rodale's New Shelter, July/August 1980.)

Chapter 12

All Through the House: a Guide to Home Weatherization, Thomas Blandy and Denis Lamoureaux.
(McGraw-Hill Book Company, New York, NY, 1980.)

Energy Savers Catalog, editors of Consumer Guide.
(Publications International, Ltd., 1977.)

547 Easy Ways to Save Energy in Your Home, Roger Albright.
(Garden Way Publishing, Charlotte, VT, 1978.)

The Fuel Savers: a Kit of Solar Ideas for Existing Homes, Dan Scully, Don Prowler, and Bruce Anderson.
(Brick House Publishing Co., Inc., Andover, MA, 1978.)

Home Energy for the Eighties, Ralph Wolfe and Peter Clegg.
(Garden Way Publishing, Charlotte, VT, 1979.)

The Home Energy Guide: How to Cut Your Utility Bills, John Rothchild and Frank Tenney.
(Ballantine Books, New York, NY, 1978.)

"Home Insulation" and "Caulking and Weatherstripping," Consumer Information Guides.
(J.C. Penney, Co., Inc., New York, NY.)

How to Save Energy and Money in Your Home, New York State Energy Office, Public Service Commission, and gas and electric utilities of New York State.
(New York State Energy Office, Albany, NY.)

"Landscape to Save Energy", Energy Facts.
(Cooperative Extension, New York State Energy Office, Albany, NY.)

Natural Solar Architecture: a Passive Primer, David Wright.
(Van Nostrand Reinhold Co., New York, NY, 1978.)

"PS Energy House", Richard Stepler.
(Popular Science, August 1980.)

Tips for Energy Savers.
(U.S. Department of Energy, Technical Information Center, Oak Ridge, TN.)

Window Design Strategies to Conserve Energy, National Bureau of Standards Building Science Series 104.
(U.S. Department of Commerce and the National Bureau of Standards, Washington, DC, 1977.)

Chapters 13, 14, and 15

"Advantages of Active", Frederic S. Langa.
(Rodale's New Shelter, January 1981.)

"Advice from a Troubleshooter", James Easterly.
(Solar Age, October 1979.)

Build Your Own Solar Water Heater, Stu Campbell.
(Garden Way Publishing, Charlotte, VT, 1978.)

Buying Solar, Joe Dawson.
(Federal Energy Administration, Washington, DC, 1976.)

"Collector Location: No Taboos on East or West", Winslow Fuller.
(Solar Age, December 1980.)

"Controls Demystified", Vic Reno.
(Solar Age, July 1980.)

"Don't Get Burned By Solar Rip-Offs", Stuart Diamond.
(Popular Mechanics, June 1980.)

Engineer's Guide to Solar Energy, Yvonne Howell and Justin Bereny.
(Solar Energy Information Service, San Mateo, CA, 1979.)

"The Fundamentals of Site-Built Collector Design", Joe Kohler and Peter Temple.
(Solar Age, July 1980.)

Home Guide to Solar Heating and Cooling, Jackson Hand.
(Book Division, Times Mirror Magazines, Inc., 1978.)

Homeowner's Guide to Solar Water Heater Troubleshooting, Ross McCluney and Tim Merrigan.
(Florida Solar Energy Center, Cape Canaveral, FL, 1981.)

Hot Water from the Sun, Franklin Research Center.
(U.S. Department of Housing and Urban Development, Washington, DC, 1980.)

The Montana Renewable Energy Handbook, prepared by Jan Konigsberg.
(Department of Natural Resources and Conservation, Helena, MT, 1981.)

"New Heat Collectors Harness More Energy from the Sun".
(Farm Journal, August 1980.)

Other Homes and Garbage: Designs for Self-Sufficient Living. Jim Leckie, Gil Masters, Harry Whitehouse, and Lily Young.
(Sierra Club Books, San Francisco, CA, 1975.)

"Our Down-to-Earth Series on Solar Hot Water", Frederic S. Langa.
(Rodale's New Shelter, July/August 1980.)

"SDHW Systems: What Experts Look For", Daniel C. Lewis.
(Solar Age, February 1979.)

The Solar Energy Notebook, William H. Rankins, III and David A. Wilson.
(Lorien House, Black Mountain, NC, 1976.)

Solar Factsheet: Flat-Plate Solar Collector Orientation, Franklin Research Center.
(U.S. Department of Housing and Urban Development, Washington, DC.)

The Solar Home Book, Bruce Anderson with Michael Riordan.
(Brick House Publishing Co., Harrisville, NH, 1976.)

"The Solar Wood Connection", Joe Carter and Richard Conrat.
(Solar Age, September 1979.)

Survey of Coatings for Solar Collectors, G.E. McDonald.
(NASA Technical Memorandum, NASA TMX-71730.)

Chapter 16

Applied Solar Energy: An Introduction, Aden B. Meinel and Marjorie P. Meinel.
(Addison-Wesley Publishing Co., Inc., Reading MA, 1976.)

"Concentrating Collectors", A.B. Meinel.
(Solar Energy Engineering, edited by A.A.M. Sayigh, Academic Press, NY, 1977.)

Engineer's Guide to Solar Energy, Yvonne Howell and Justin Bereny.
(Solar Energy Information Service, San Mateo, CA, 1979.)

"The French CNRS 1000 kW Solar Furnace: Description, Performance Characteristics, Present Utilization, and Perspectives", F. Trombe, A. LePhat Vinh, and C. Royere and "Solar Thermal Power Systems", Jesse C. Denton.
(Alternative Energy Sources, edited by James P. Harnett, Hemisphere Publishing Corporation, Washington, DC, 1976.)

"The Inexhaustible Source", Jane Moulton.
(WE [Western Electric], July-August 1979.)

"Power with Heliostats", Alvin F. Hildebrandt and Lorin L. Vant-Hull.
(Science, 16 September 1977.)

"Prospects for Solar Industrial Process Heat".
(Solar Engineering, March 1980.)

"Solar Collector/Converter Moves Heat in Chemical Form", Richard Stepler.
(Popular Science, June 1980.)

"Solar Thermal Energy: Bringing The Pieces Together", William D. Metz.
(Science, 12 August 1977.)

Chapter 17

"Energy from Space", Ann Seltz-Petrash.
(Civil Engineering, July 1979.)

Energy from the Sun, D.M. Chapin.
(Bell Telephone Laboratories, Inc., 1962.)

"Photovoltaics: Milestones Passed, Miles Ahead", Bill D'Allesandro.
(Solar Age, December 1979.)

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

Solar Energy for Man, B.J. Brinkworth.
(John Wiley & Sons, New York, NY, 1972.)

"Solar Satellites: the Trillion Dollar Question", J. Kelly Beatty.
(Science 80, December 1980.)

"Sunshine into Electricity", John Free.
(Popular Science, April 1981.)

Chapter 18

"Can We Harness the Wind?", Roger Hamilton.
(National Geographic, December 1975.)

Catch the Wind: A Book of Windmills and Windpower, Landt Dennis.
(Four Winds Press, New York, NY, 1976.)

"Energy Out of Thin Air", Frederic S. Langa.
(Rodale's New Shelter, November/December 1980.)

"How to Make a Wind-Site Analysis", Jeanne McDermott.
(Popular Science, July 1980.)

"New Energy: a Burgeoning Business in Windmills".
(New York Times, April 27, 1980.)

"Should You Put a Windmill in Your Yard?", Ron Ross.
(The Family Handyman, October 1980.)

"Will It Pay You To Put Up a Windmill?", John J. Pullen.
(Blaire & Ketchum's Country Journal, July 1980.)

"Wind Energy", New York State Electric & Gas Corp.
(NYSE&G Notes, February 1977.)

"Wind Energy: Large and Small Systems Competing".
(Science, September 2, 1977.)

"Wind Power and Windmills", U.S. Dept. of Agriculture.
(U.S. Government Printing Office, March 1980.)

"Wind Power" NSTA Factsheet, John M. Fowler and Kathryn Mervine Fowler.
(U.S. Department of Energy, Technical Information Center, Oak Ridge, TN.)

Wind Power for Farms, Homes, and Small Industry, Jack Park and Dick Schwind.
(National Technical Information Service, September 1978.)

Wind Power for the Homeowner, Donald Marier.
(Rodale Press, Emmaus, PA, 1982.)

"Winners or Losers? Energy Experts Evaluate Thirteen Wind Machines", Victor Chase.
(Popular Science, September 1978.)

"World's Biggest Wind Machine is a One-Armed Monster", David Scott.
(Popular Science, January 1981.)

Chapter 19

"Developing a Small Hydro-Electric System", Mike Johnson.
(Alternative Sources of Energy #46, November/December 1980.)

Harnessing Water Power for Home Energy, Dermot McGuigan.
(Garden Way Publishing Co., Charlotte, VT, 1978.)

Home Energy for the Eighties, Ralph Wolfe and Peter Clegg.
(Garden Way Publishing Co., Charlotte, VT, 1979.)

Low Cost Development of Small Water Power Sites, Hans W. Hamm.
(VITA, Inc., Mt. Rainier, Maryland, 1967.)

Micro-Hydro Power, Ron Alward et al.
(National Center for Appropriate Technology, Butte, MT, 1979.)

Micro-Hydro Power: Reviewing an Old Concept, U.S. Department of Energy.
(National Technical Information Service, Springfield, VA, 1979.)

"Now: Energy by the Bucket from Backyard Power Plants", John Ingersoll.
(Popular Mechanics, February 1981.)

"Power from the Streams", Helene S. Kassler.
(Solar Age, July 1978.)

"Water Over the Dam?", Karen Magnuson Beil.
(The Conservationist, June-July 1974.)

The World of Energy Storage, Waldo T. Boyd.
(G.P. Putnam's Sons, NY, 1977.)

Chapter 20

Biomass Energy.
(U.S. Department of Energy, Washington, DC, 1980.)

"Biomass Energy from Crop and Forest Residues", David Pimentel et al.
(Science, Vol. 212, June 5, 1981.)

"Biomass Energy: the Promise and the Problems", William Lockeretz.
(Sierra, January/February 1979.)

Biomass: Solar Energy from Farms and Forests.
(Solar Energy Research Institute, Golden, CO, August 1979.)

Burning Wood.
(Cooperative Extension Services, Cornell University, Ithaca, NY.)

"A Clean Burn", Robert Deis.
(Blair & Ketchum's Country Journal, October 1979.)

The Complete Book of Composting, ed. J.I. Rodale.
(Rodale Books Inc., Emmaus, PA.)

Energy from Biological Processes.
(Office of Technology Assessment, Congress of the U.S., July 1980.)

Food or Fuel: New Competition for the World's Cropland, Lester R. Brown.
(Worldwatch Institute, Washington, DC, March 1980.)

Fuel from Farms, Solar Energy Information Data Bank.
(Solar Energy Research Institute, Golden, Colorado, May 1980.)

"Fuels from Plants: Bioconversion", NSTA Factsheet, John M. Fowler and Kathryn Mervine Fowler.
(U.S. Department of Energy, Technical Information Center, Oak Ridge, TN.)

"Fuels from Wastes: Bioconversion", NSTA Factsheet, John M. Fowler.
(U.S. Department of Energy, Technical Information Center, Oak Ridge, TN.)

"Gasohol: A Choice that May Buy Grief",
(Science, Vol. 207, No. 4438, March 28, 1980.)

Global Food Assessment, 1980.
(U.S. Department of Agriculture, Washington, DC, 1980.)

On the Farm Methane.
(Bio-Gas of Colorado, Inc., Arvada, Colorado, 1980.)

Other Homes and Garbage, Jim Leckie et al.
(Sierra Club Books, San Francisco, CA, 1975.)

"Overview: Biomass as a Source of Energy", Nicholas P. Cheremisinoff.
(Alternative Sources of Energy, #48, March/April 1981.)

"Photosynthetic Solar Energy: Rediscovering Biomass Fuels, Allen L. Hammond.
(Science, August 19, 1977.)

Small Scale Fuel Alcohol Production.
(U.S. Department of Agriculture, Washington, DC, 1980.)

"The Solar Wood Connection", Joe Carter and Richard Conrat.
(Solar Age, September 1979.)

The State of the World Atlas, Michael Kidron and Ronald Segal.
(Simon & Schuster, New York, 1981.)

"Ten Ways to Avoid Woodstove Fires", Ron Ross.
(Family Handyman, September 1980.)

"Thought Snacks: What's Your Steak?", Thomas Hanna.
(Human Ecology Forum, Vol. 8, No. 3, Winter, 1978.)

Wood: An Ancient Fuel with a New Future, Nigel Smith.
(Worldwatch Institute, Washington, DC, 1981.)

"Woodburning Furnace", Larry Gay.
(Blair & Ketchum's Country Journal, October 1979.)

The Woodburner's Encyclopedia, Jay Shelton.
(Vermont Crossroads Press, Waitsfield, VT, 1976.)

Wood Heat, John Vivian.
(Rodale Press, Inc., Emmaus, PA, 1976.)

"Wood Stove Checklist", David Bear.
(Rodale's New Shelter, October 1980.)

Chapter 21

"Ocean Energy: Forms and Prospects", John D. Isaacs and Walter R. Schmitt.
(Science, Vol. 207, January 18, 1980.)

"Energy from the Ocean: A Look at Tidal Power", Roger H. Charlier.
(Alternative Sources of Energy #50, July/August 1981.)

"Power from the Sea", Mark Swann.
(Environment, May 1976.)

Geothermal Energy, William W. Eaton.
(U.S. Energy Research and Development Authority, Washington, DC, 1975.)

Geothermal Energy.
(Union Oil Co. of California, Los Angeles, CA.)

Optimization of Geothermal Home Heating Systems, G. Gene Culver.
(Idaho National Engineering Laboratory, Idaho Falls, Idaho, 1976.)

"Geothermal Energy: Prospects and Limitations", Hamilton Hess.
(Sierra Club Bulletin, November/December 1976.)

"Geothermal Energy", NSTA Factsheet, John M. and Kathryn Mervine Fowler.
(U.S. Department of Energy, Technical Information Center, Oak Ridge, TN.)

"Geothermal Energy", New York State Electric & Gas Corp.
(NYSE&G Notes, April 1977.)

"Using the Earth's Heat", Morton C. Smith.
(The Conservationist, August/September 1974.)

Chapter 22

"A City Changes Its Energy Future", Katherine Alvord and Michael R. Eaton.
(Sierra, May/June 1979.)

"A Commentary on Solar Access: Less Theory, More Practice", Martin Jaffee.
(Solar Law Reporter, Vol. 2, No. 4.)

"Energy Saving--Tax Benefits".
(Insulation Reporter, Mineral Insulation Manufacturers Association, August 1981.)

"Guidebook Resources for Local Governments".
(U.S. Department of Energy, Washington, D.C., April 1981.)

"Institutional Barriers to Solar Energy", Gerald Mara and David Engel.
(Solar Law Reporter, Vol. 1, No. 6, March/April 1980.)

"IRS Is Picky About Tax Breaks for Passive", Arnold R. Wallenstein.
(Solar Age, July 1981.)

"Legal Obstacles to Decentralized Solar Energy Technologies", Alan S. Miller.
(Solar Law Reporter, Vol. 1, No. 3.)

"Siting = Protection: A Note on Solar Access", Dale D. Goble.
(Solar Law Reporter, Vol. 2, No. 1.)

Solar Access: It's the Law, Robert L. Thayer, Jr. ASLA.
(University of California, Davis, CA, 1981.)

Solar Legislation.
(National Solar Heating and Cooling Information Center, Rockville, MD, 1980.)

"Solar Power Means New Utilities Role", Dick Kirschten.
(National Journal, October 6, 1979.)

"The Sun: Who Owns It?", Earl A. Talbot and Dawn Walter.
(The Appraisal Journal, October 1979.)

"The Transition to a Post-Petroleum World", Denis Hayes.
(Journal of Home Economics, May 1978.)

Metric Conversion Table

Unit of Measure	English Unit	Multiply By ► ◄ Divide By	Metric Unit	Symbol
Length	inches	2.54	centimeters	cm
	feet	30.0	centimeters	cm
	feet	0.3	meters	m
	yards	0.91	meters	m
	miles	1.61	kilometers	km
Area	square inches	6.5	square centimeters	cm^2
	square feet	0.09	square meters	m^2
	square yards	0.8	square meters	m^2
Mass (Weight)	ounces	28	grams	g
	pounds	0.45	kilograms	kg
Volume	gallons	3.8	liters	l
	cubic feet	0.03	cubic meters	m^3
Temperature	degrees Fahrenheit	5/9 (after subtracting 32) 5/9 plus 32	degrees Celsius	°C
Heat	Btu	252	calories	c
Speed	miles per hour	1.61	kilometers/hour	km/hr

Energy Units

barrel: a liquid volume equal to 42 gallons or 159 liters. One barrel of crude oil has about the same heat energy as 350 pounds of bituminous coal, 5.8×10^9 joules or 5.5×10^6 Btu or 1.39×10^6 kcal.

Btu: British thermal unit, a unit for measuring heat; a Btu is the quantity of heat necessary to raise the temperature of one pound of water one degree Fahrenheit, about one-fourth of a kilocalorie (252 calories).

calorie (also: gram calorie): a metric unit of heat energy; the amount of heat needed to raise the temperature of one gram of water one degree Celsius. It equals 0.0039 Btu. One thousand calories make one kilocalorie (kcal), sometimes called a Calorie or food Calorie.

kilowatt: a measure of power, usually electrical power or heat flow; equal to 1,000 watts or 3,413 Btu per hour.

kilowatt-hour: the amount of energy equivalent to one kilowatt of power being used for one hour; equals 3,413 Btu, or about 860 kcal.

watt: a unit of measure for electrical power equal to the transfer of one joule of energy per second. The watt is the unit of power most often associated with electricity and is determined by multiplying required volts by required amperes. One horsepower = 746 watts.

To Production Support

4-30-85
Patty H.