Edward Allen

HOW BUILDINGS WORK

The Natural Order of Architecture

THIRD EDITION

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THE NATURAL ORDER OF ARCHITECTURE

Third Edition

EDWARD ALLEN

Drawings by David Swoboda and Edward Allen

OXFORD
UNIVERSITY PRESS
2005

OXFORD
UNIVERSITY PRESS

Oxford University Press, Inc., publishes works that further
Oxford University's objective of excellence
in research, scholarship, and education.

Oxford New York
Auckland Cape Town Dar es Salaam Hong Kong Karachi
Kuala Lumpur Madrid Melbourne Mexico City Nairobi
New Delhi Shanghai Taipei Toronto

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Argentina Austria Brazil Chile Czech Republic France Greece
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Published by Oxford University Press, Inc.
198 Madison Avenue, New York, New York 10016
www.oup.com

Library of Congress Cataloging-in-Publication Data
Allen, Edward.
How buildings work : the natural order of architecture / Edward Allen.—3rd ed.
p. cm.
Includes bibliographical references and index.
Cover title: Natural order of architecture.
ISBN-13: 978-0-19-516198-4
ISBN-10: 0-19-516198-X
1. Buildings—Environmental engineering.
I. Title: Natural order of architecture. II. Title.

TH6021.A44 2004
721—dc22 2004021414

9 8 7 6 5 4 3 2 1
Printed in the United States of America
on acid-free paper

With thanks to the people
who helped make it happen:

JOYCE BERRY

NOEL CARR

ALBERT G. H. DIETZ

ELLEN R. FUCHS

N. J. HABRAKEN

CATHERINE HUMPHRIES

FRANK JONES

DONLYN LYNDON

DOUGLAS MAHONE

JAMES RAIMES

ELDA ROTOR

J. N. TARN

CYBELE TOM

WACLAW ZALEWSKI

and especially

MARY M. ALLEN

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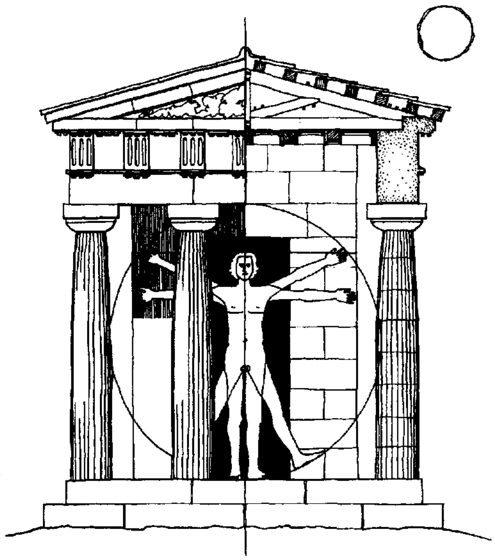
Preface
to the Third Edition

Over the past quarter century, the practice of building has undergone significant changes in several areas, notably mechanical, electrical, and communications systems. Researchers have added to our knowledge of building function. New areas of social concern have emerged, especially for buildings that are accessible by all, and for building in a sustainable manner. This third edition, in the tradition of its predecessors, sticks to the basics, but includes hundreds of changes both large and small that reflect the current state of the art and science of building. I have retained the basic organization of the original volume, along with its look and feel, all of which have worn well. The mission and premise of the book remain unchanged.

South Natick, Massachusetts
January 2005

E. A.



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Prologue: Sustainable Building

Buildings represent a huge investment, not only of money and time, but also of the world's resources. In constructing and occupying buildings, we consume vast quantities of materials and generate a major portion of the world's environmental pollution. According to the Worldwatch Institute, buildings consume more than 40 percent of the energy utilized in the world each year and, in so doing, release into the atmosphere one-third of the carbon dioxide and two-fifths of the compounds that cause acid rain. In the United States, our buildings use about one-sixth of the fresh water consumed each year and a quarter of harvested wood. Our buildings release about half of the fluorocarbons that escape into the upper atmosphere and destroy the ozone layer that shelters us from the sun's ultraviolet rays. About 40 percent of our landfill material comes from construction projects. We see in these statistics that buildings are responsible for many forms of environmental degradation. They place a heavy burden on the earth's resources, most of which are nonrenewable and finite, and they jeopardize the health and welfare of humanity. Thus it is increasingly urgent that we learn to build and operate buildings in a sustainable manner.

Sustainability may be defined as *meeting the needs of the current generation without compromising the ability of future generations to meet their needs*. When we burn fossil fuels, we consume a portion of a finite, nonrenewable resource so that it will not be available a generation or two in the future. We also generate greenhouse gases that promote global warming. This will confront a near-future generation with the problem of a world in which glaciers and ice caps are shrinking, seas are rising to perilous levels, and weather is violent and unpredictable. When we build sprawling residential subdivisions on fertile land once used for growing food crops, we reduce the stock of agricultural land that will be available to future generations. When we use wood from forests that are not replanted with trees, we make it more likely that our children and grandchildren will find wood to be a scarce, expensive commodity.

We have it in our power to change this situation. We can reduce substantially the energy needed by our buildings. We can meet much of this need with solar and wind energy, both of which are renewable, nonpolluting, and available on the site itself. In many instances, we can build on land that has been recovered from abusive practices of the past such as contaminated industrial sites, demolished tenement apartment buildings, and land on which poor agricultural practices have led to extensive soil erosion. We can build with wood from certified forests, ones that are harvested and replanted in such a way that they will produce wood forever. We can build with wood recovered from old buildings that have been taken down. In each of these examples, we are building in such a way as to pass on to future generations the means to build in a similar fashion.

A number of organizations and manufacturers are working diligently toward sustainable construction practices (also referred to as *"green" building*). Some relate to particular resources such as forests. Some have to do with recycling materials such as scraps of gypsum wallboard or worn-out tires into new building materials: gypsum wallboard, roofing slates. Some are promoting renewable energy sources such as solar, wind, and photovoltaic technologies. Some concentrate on improving the energy performance of buildings through better thermal insulation, more airtight construction, and more efficient heating and cooling machinery. And some focus on educating architects and engineers, the designers of buildings, who by siting and orienting buildings intelligently, configuring them appropriately, selecting materials knowingly, and detailing the construction properly, can greatly reduce their impact on the earth and its resources.

Several organizations are working to educate architects and engineers in how to build sustainably. Prominent among these is the United States Green Building Council, which sponsors the LEED system for evaluating the sustainability of a building. LEED stands for Leadership in Energy and Environmental Design. The evaluation process is summarized by a checklist that is used in evaluating the degree of sustainability that is attained in a building. It is instructive to look at the categories on this checklist. The first broad category, "Sustainable Sites," includes, among other factors

- whether a building will improve its site or degrade it;
- whether the users of the building will be able to come and go by foot, on bicycles, or by public transportation so as to save fuel and reduce air pollution;

- the extent to which the site is disturbed by the new construction; and
- how storm water is managed (is it stored for use on-site, used to recharge the aquifer in the area, or dumped into a storm sewer?).

The second category, "Water Efficiency," includes

- use of stored storm water or "gray" wastewater (discarded wash water that does not contain human wastes) for irrigation;
- innovative wastewater treatment; and
- use of fixtures that reduce water consumption.

Category 3, "Energy & Atmosphere," relates to

- efficiency of the building's heating and cooling devices and systems;
- use of renewable energy resources on the site; and
- the potential of the building to contribute to ozone depletion.

Category 4 is "Materials & Resources." It includes

- recycling of building materials and building wastes;
- waste management on the construction site;
- recycled content in building materials used;
- use of local and regional materials, which consume less fuel in transportation, rather than materials that must be transported long distances;
- rapidly renewable materials; and
- wood from certified forests.

"Indoor Environmental Quality," the title of the fifth category, covers

- indoor air quality;
- elimination of tobacco smoke;
- ventilation effectiveness;
- air quality during construction;
- use of materials that do not give off toxic gases;
- control of chemicals used in the building;
- thermal comfort; and
- use of daylighting.

The sixth and last category is titled "Innovation & Design Process." It is an open category that awards credits for original design ideas that lead to more sustainable buildings. It also awards credits if an architect or engineer who has been accredited as a LEED expert is involved in the design of the project.

Although this list is still evolving, it is already serving as the basis for certifying the degree to which a building is sustainable. Additionally, it is a powerful vehicle for raising the environmental awareness of architects, engineers, and builders.

Throughout the pages that follow, you will find information relating to sustainability in the design, construction, and operation of buildings. Every chapter tells how to build in such a way that resources are used wisely, energy is conserved, waste products are reduced, and buildings are made comfortable, durable, and healthy with the minimum possible cost to the environment. Many of these practices are old and well-known. Some are new and innovative. In either case, architects and engineers must become familiar with them and use them more consistently if we are to pass on to our children and grandchildren a world as lovely, hospitable, healthy, and resource-rich as the world into which we were born.

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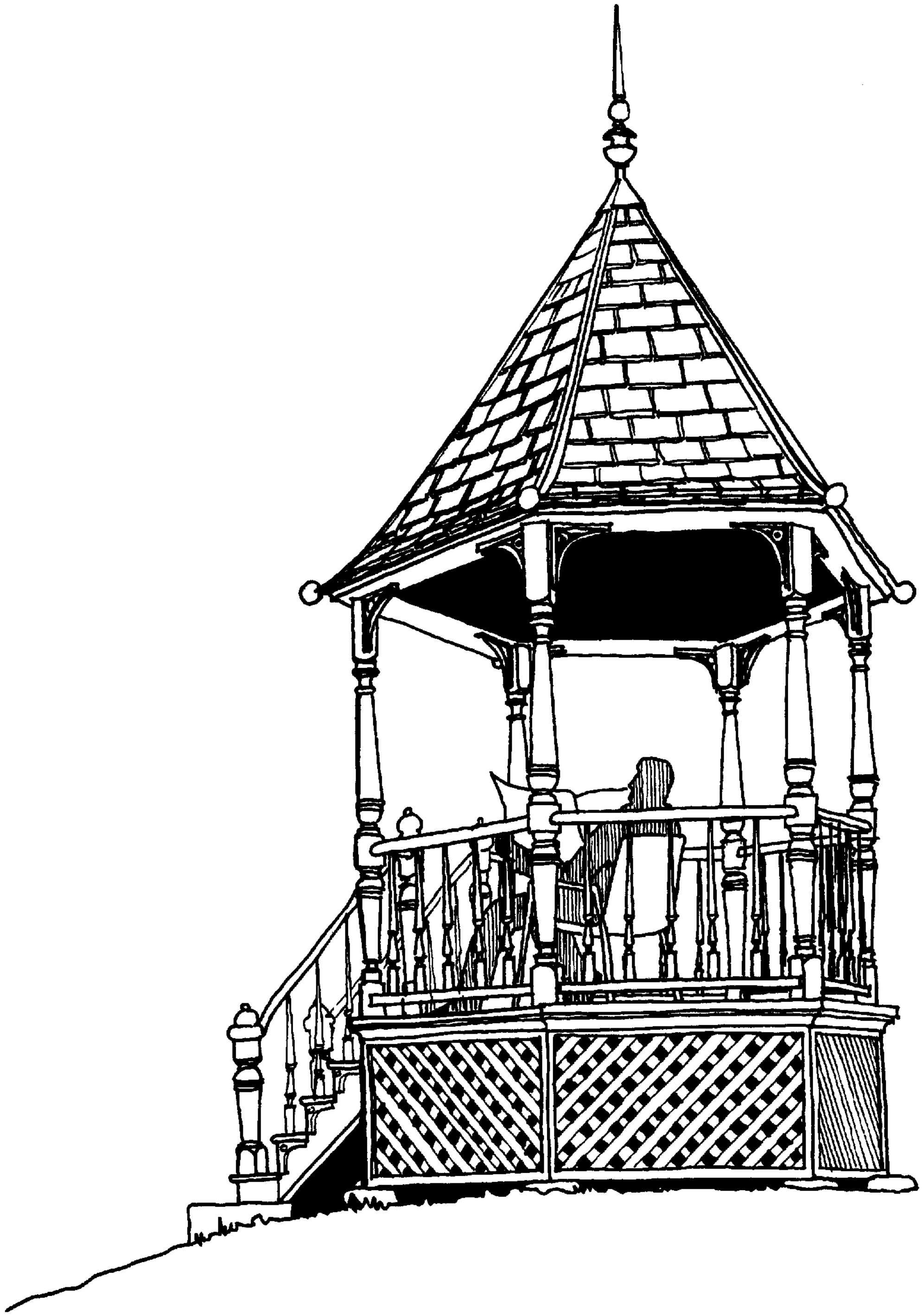
What Buildings Do



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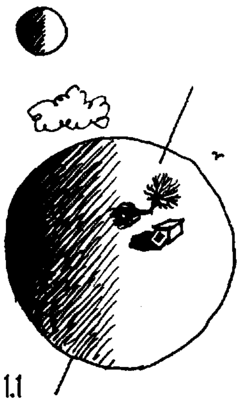
1
The Outdoor Environment

The Earth and the Sun

Earth is unique among the planets of our solar system in offering all the basic necessities of life. But human life is far from easy on most parts of the globe. A planet-sized atmospheric engine, fueled by radiation from the sun and cooled by the radiation of heat back into the emptiness of space, moves air, moisture, and thermal energy across its surface in restless patterns that create an outdoor environment of varied and often extreme conditions.

The sun is the single most important factor in the lives of people and their buildings. The oxygen we breathe, the food we eat, and the fuels we burn are created by the action of sunlight on green plants. The water we drink is purified in an atmospheric distillation process powered by heat from the sun. Sunlight warms our bodies and buildings by direct radiation or through warming the air around us, sometimes enhancing our comfort and other times making us uncomfortable. Sunlight illuminates the outdoors, disinfects the surfaces it touches, creates vitamin D in our skin, and has an uplifting effect on our dispositions. Sunlight also disintegrates the materials with which we build, burns our skin, and promotes skin cancer. The sun is both the giver of life and its destroyer.

Sunlight includes electromagnetic radiation of varying wavelengths. Fewer than 1 percent of the sun's rays that reach sea level on earth are too short in wavelength to be visible. These ultraviolet rays range between about 160 and 400 nanometers (nm) in wavelength. The visible solar wavelengths, ranging between 400 and 780 nm, contain about half the energy of sunlight. The other half of the energy lies in the infrared part of the spectrum, the invisible wavelengths between 780 and 1500 nm. (A nanometer is one-billionth of a meter. A dime is about one million nanometers thick.)



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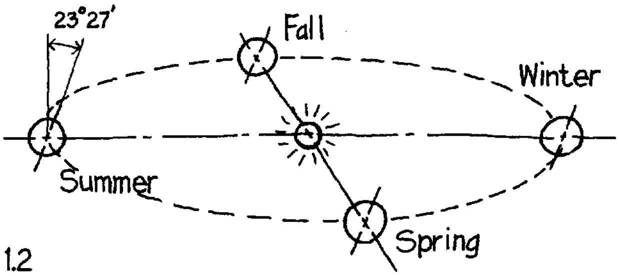

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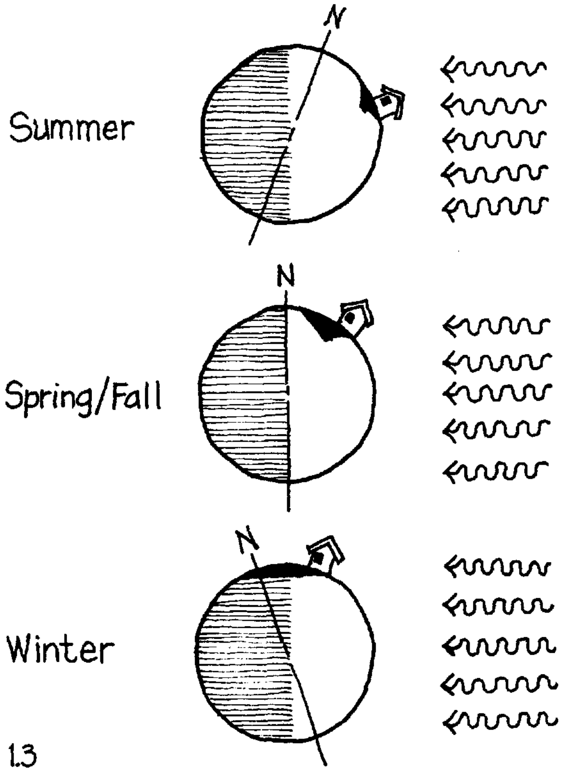

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The earth loops around the sun in a slightly elliptical orbit with a mean radius of 92.9 million miles (149.5 million kilometers). It rotates about its own axis once each day and completes an orbit every 365¼ days. The half of the globe that is oriented away from the sun at any moment is in darkness, and the other half is sunlit (1.1). The earth's orbit is out of round by about 3 percent. Thus the distance between the earth and the sun changes enough to cause a variation of about 7 percent in the intensity of solar radiation on the earth over a six-month period. However, this variation is not the creator of the earth's seasons. In fact, the earth is closest to the sun in winter, so the orbital eccentricity helps slightly to moderate the seasons. The seasons are created, instead, by the tilt of 23°27′ between the axis of the earth's rotation and a perpendicular to the plane of its orbit (1.2).

The Summer Solstice

At the position in the earth's orbit where the North Pole is tilted closest to the sun, the sun's rays in the Northern Hemisphere pass through the atmosphere and strike the earth's surface at a steep angle (1.3). The path of the rays through the atmosphere is short, so that the air absorbs and scatters relatively little sunlight before the radiation reaches the ground. Because the sun is so high with respect to the surface of the land in the northern hemisphere, solar radiation is received in a maximum concentration per unit area of soil. The sun's rays are at their hottest at this orbital position, known as the *summer solstice*, which occurs about June 21 of each year. The total solar heat gathered by the Northern Hemisphere on June 21 is further increased by another important factor: the sun is seen for a longer period of time on this day than on any other day of the year. The sun rises to the north of east before six o'clock in the morning and sets to the north of west after six o'clock in the evening. How long before and after six o'clock sunrise and sunset occur is wholly dependent on latitude. On the equator, the day from sunrise to sunset is always 12 hours long regardless of the time of year. Moving northward to the Tropic of Cancer, June 21 is only slightly longer than 12 hours, and the sun at noon appears directly overhead at an altitude of exactly 90°. (The Tropic of Cancer is at 23°27′ north latitude, the same angle as the inclination of the earth's axis.) As we move farther and farther to the north, we find that June 21 has longer and longer hours of sunlight, with the sun rising and setting farther and farther toward the north, until at the Arctic Circle the sun never sets at all but merely skims the horizon at midnight, giving 24 hours of sunlight. Simultaneously, however, the noontime sun's altitude decreases as one moves northward, from 90° at the Tropic of Cancer, to 70° at the latitude of New York City, to 47° at the Arctic Circle, and to 23°27′ at the North Pole. This reduces the heating effect of the sun on the earth's surface so that, in general, the farther north one goes, the cooler the climate will be.

Not surprisingly, the summer solstice occurs during the warm season of the year. On the average, however, the hottest weather of the year comes four to six weeks later than the summer solstice, in late July and early August. This delay occurs because the land and water absorb and hold considerable solar heat during the warmer days of the year. By late in the summer, however, the earth gives back this stored energy to the cooler air, thus moderating the effect of the lower solar flux in that season.

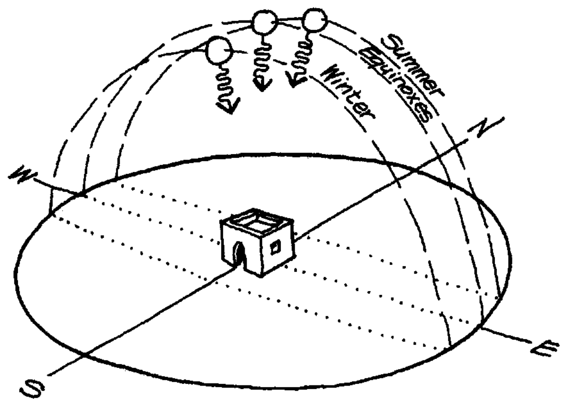
In the opposite orbital position, which occurs about December 21, the *winter solstice* in the Northern Hemisphere, the North Pole is tilted directly away from the sun. The sun's rays arrive at a low angle to the surface of the earth after losing much of their energy in a long, flat passage through the atmosphere, and their heating effect on the ground is correspondingly weak. This day has the fewest hours of sunlight of any day of the year, with the sun rising late and to the south of east, climbing to a low noontime, and setting early and to the south of west. Above the Arctic Circle, the sun never rises at all but appears as a faint glow in the southern sky at midday. The land and seas are still giving off stored heat from the warmer autumn days, however, so that the coldest part of the winter does not come until late January or early February.

The Equinoxes

On or about March 21 and September 21, known respectively as the *vernal equinox* and the *autumnal equinox*, the North and South Poles are equidistant from the sun. Everywhere on earth, the sun rises exactly in the east and sets exactly in the west 12 hours later, except at the extreme poles, where the sun travels just along the horizon for 24 hours.

The Annual Cycle

It is useful to keep in mind that the seasonal variations in length of day and the maximum daily sun altitude are least pronounced in the tropics and most exaggerated in the polar regions. In the tropics, the length of day is always close to 12 hours but, except on the equator itself, is slightly longer in summer and slightly shorter in winter. The sun always rises in the vicinity of due east, a bit to the north in summer and a bit to the south in winter, and sets in the vicinity of due west, traveling very nearly directly overhead at noon. The sun always



Equatorial Zone
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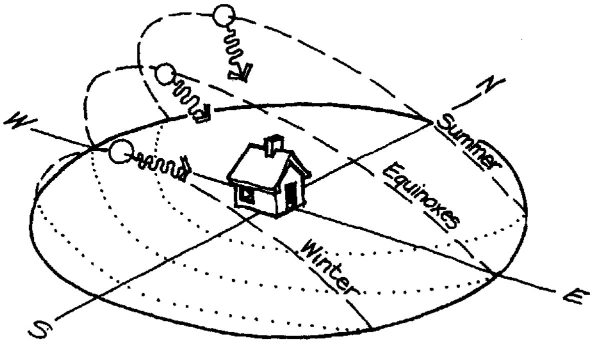

Temperate Zone
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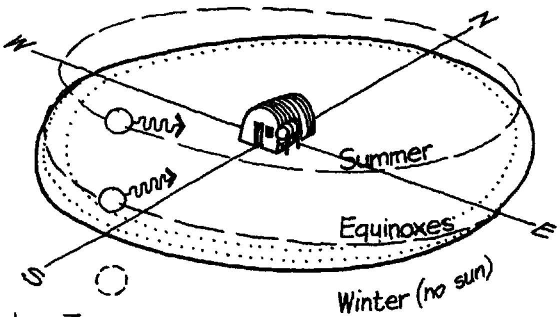


Polar Zone
1.6

intercepts the horizon in the mornings and evenings at a steep angle, producing very brief sunrises and sunsets (1.4).

As one moves northward in latitude, seasonal variations increase gradually. Summer days are longer than they are in the tropics, and winter days are shorter. Noontime sun altitudes are lower, giving a lower solar flux per unit of ground area. The directions of sunrise and sunset show a more marked seasonal swing, and sunrises and sunsets are more prolonged (1.5). In the Northern Hemisphere the limiting case is the North Pole, where day and night each are six months long: the sun rises on March 21, climbs to a low "noon" on June 21, and sets on September 21 (1.6). Over the course of a year, every point on the globe is exposed to direct sunlight exactly half the time. At the poles, the half portion of sunlight comes in one continuous six-month period. At the equator, each day of the year is evenly divided between sunlight and darkness. At intermediate latitudes, longer days in summer compensate for shorter ones in winter.

In the Southern Hemisphere, the sun resides in the northern half of the sky, and the seasons are reversed from those in the Northern Hemisphere, with longer days and higher solar fluxes occurring while the days are short and the sunlight is weak in the Northern Hemisphere. The progression of seasonal effects from the equator to the pole is the same as for the Northern Hemisphere.

Effects of Solar Radiation on the Earth

A number of factors affect the amount of solar radiation that reaches a particular surface. As we have already seen, these include the length of day, the angle of incidence of sunlight on the ground at each time of day, and the amount of atmosphere traversed by the radiation at each time of day. Of these three, atmospheric interference is the most difficult factor to evaluate. Solar intensity just outside the earth's atmosphere is about 130 watts per square foot (1,400 watts/m^2). At an altitude of about 15 miles, a stratum of ozone and nascent oxygen absorbs most of the ultraviolet portion of the solar waves. In the lower reaches of the atmosphere, carbon dioxide, water vapor, clouds, dust, and pollutants work in various ways to reflect, scatter, absorb, and reradiate different parts of the spectrum. The shorter wavelengths of sunlight, which are the most affected, produce the blue appearance of the daytime sky. A considerable portion of the sunlight's energy is stripped away by the "clear" atmosphere—nearly half, on the average, worldwide. Most of this energy is then reradiated from the atmosphere into space, but a significant amount is reradiated from the atmosphere to the earth as diffuse sky radiation, thus slightly increasing the total amount of solar energy available at the earth's surface. Clouds, which cover roughly half the earth's surface at any given time, block much of the sun's direct radiation but still pass a considerable quantity in diffuse form.

Taking all these factors into account, a square foot of land at 45° latitude, in a location with a 50 percent incidence of cloud cover, receives about 75 kilowatt-hours of direct solar radiation each year, plus roughly another 20 kilowatt-hours of diffuse sky radiation, for a total of nearly 100 kilowatt-hours annually. A square meter of land receives almost 11 times these quantities.

The sun imparts little heat directly to the earth's atmosphere. Instead, the ground and objects on it are warmed by solar radiation, and they in turn pass some of their heat to the air. The rate at which a patch of ground is warmed depends on several factors, beginning with the amount of solar energy that arrives at the surface. Assuming equal atmospheric conditions, a patch of ground nearer the equator receives more solar heat than one farther from the equator because of the higher angle of incidence of the sun's rays on the ground. For much the same reason, a south-facing hillside receives a higher intensity of sunlight than a flat field, and a steeply north-facing slope may receive none at all.

A second factor affecting the rate at which ground is warmed is the portion of solar radiation that the ground reflects. This is typically about 20 percent, leaving 80 percent to be absorbed. Of this 80 percent, a portion may go to warm the soil and thus is stored temporarily. Some is expended in evaporating moisture from the soil. Some is radiated at long infrared wavelengths from the soil back to the sky and to cooler terrestrial objects that the patch of ground can "see": treetops, fences, buildings, and so forth. The remainder of the 80 percent warms the air above the patch of ground.

Night Sky Radiation

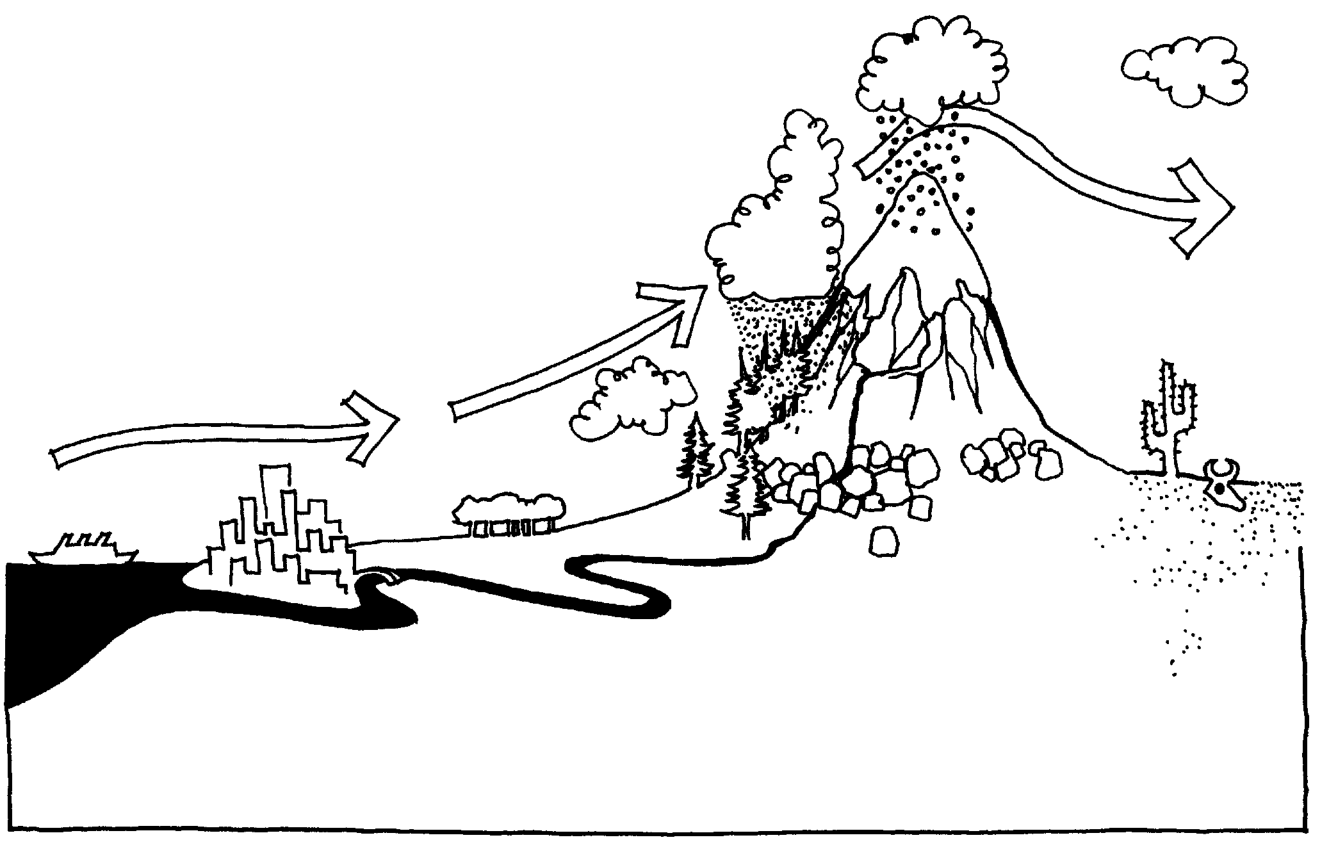
So far we have been considering the tremendous influx of solar radiation on the earth in the daytime. At night, the flow is reversed, with the dark side of the earth radiating energy into space at infrared wavelengths ranging from 4,000 to 80,000 nm, considerably longer than the sun's infrared rays. On cloudy, humid nights, water vapor in the atmosphere, which is particularly absorptive of this long-wave infrared radiation, serves to block much of the outflow of energy, but on clear, dry nights, a very powerful cooling effect is exerted by rapid radiation from the warm earth to the cold blackness of the sky. Dew frequently condenses from the air onto radiationally cooled surfaces of the ground and the roof surfaces of automobiles and buildings. These cold surfaces cool the adjacent air. A stagnant layer of cold air may form near the ground in a stable atmospheric configuration known as an *inversion*. Ground fog may form as moisture condenses in this cold layer, and frost may occur along the ground even when thermometers at eye level are reading temperatures well above freezing. A nighttime wind tends to mix earth-cooled air with warmer air, making dew, frost, and ground fog less likely to form. Over bodies of water, the large heat capacity and convective mixing of the water generally result in a less pronounced nocturnal cooling of the air than over land.

Weather

If atmospheric conditions are the same in all parts of the world, nighttime heat loss by radiation occurs at an equal rate regardless of latitude. But daytime heat gain, as we have seen, is not equal in all locations. On any day of the year, the tropics and the hemisphere that is experiencing its warm season receive much more solar radiation than do the polar regions and the colder hemisphere. Averaged over the course of the year, the tropics and latitudes up to about 40° receive more total heat than they lose by radiation. Latitudes above 40° receive less total heat than they lose by radiation. This inequality produces the necessary conditions for the operation of a huge, global-scale engine that takes on heat in the tropics and gives it off in the polar regions. Its working fluid is the atmosphere, especially the moisture it contains. Air is heated over the warm earth of the tropics, expands, rises, and flows away both northward and southward at high altitudes, cooling as it goes. It descends and flows toward the equator again from more northerly and southerly latitudes. Meanwhile, the earth's eastward rotation deflects these currents westward along the earth's surface to form the trade winds. Farther toward the poles, similar but weaker cells of air convection are set in motion, resulting in a generally eastward flow of air (1.7).

1.7

The heat of the sun evaporates water continuously from the seas and land into the air. The warm, moist air thus produced eventually rises, either because of convection or because the air is contained in winds that blow up the slopes of rising landmasses. As the air rises, it expands because of decreasing atmospheric pressure. As it expands, it undergoes adiabatic cooling until it reaches the temperature at which its moisture begins to condense. The condensing moisture evolves latent heat into the air, offsetting some of the cooling effect of expansion. But a slower rate of cooling continues as the air continues to rise; moisture continues to condense; and clouds of water droplets and ice crystals are formed. Considerable quantities of water are often involved; a single large cumulus cloud is estimated to weigh 100,000 tons (10^8 kg).

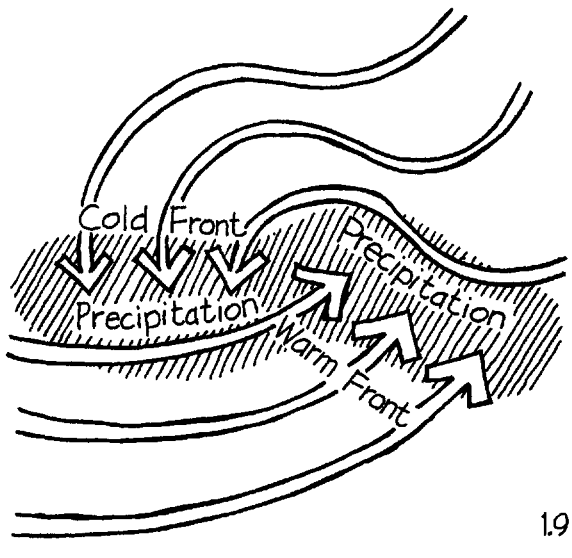


1.8

Precipitation

The exact mechanism by which a cloud releases its moisture is not well understood, but it generally involves both further cooling and the presence in the cloud of microscopic particles of dust around which the tiny cloud droplets can aggregate to form raindrops or ice crystals. Precipitation tends to be heavier over mountain ranges because of the rapid cooling of the rising winds and is usually sparse to the leeward side of mountains, where the descending winds have already been wrung dry of excess water (1.8). Rainwater and snow melt are gathered by the earth's surface into streams and rivers and eventually flow to the seas, evaporating moisture into the air along the way to start the cycle again.

In the temperate latitudes, large masses of warm, moist air from more tropical climates advance northward to meet masses of cooler, drier air from the polar regions. The warm front, characterized by low barometric pressure, and the higher-pressure cold front collide and swirl about each other, increasing local wind velocities and releasing precipitation where the warm air is suddenly cooled by contact with the cold air (1.9). Weather patterns in the temperate



1.9

latitudes are predominantly the result of such frontal systems. They are less stable and predictable than tropical weather, which is dominated by the general sun-induced circulation of the atmosphere.

Wind serves an important function in the earth's weather, distributing both water and heat more equitably about the globe. Wind flow at high altitudes is generally rapid and fairly smooth. In the vicinity of the earth's surface, however, the wind is subjected to interference from hills, mountains, trees, buildings, and various convective flows of air. The average wind speed is progressively reduced by these obstacles nearer the ground, and the wind flow becomes more turbulent, fluctuating rapidly in both velocity and direction.

The atmospheric engine converts vast quantities of energy from sunlight to wind and from sunlight to falling precipitation. Despite its being only about 3 percent efficient in transforming radiation into motion, the engine operates at a level that would be measured in trillions of horsepower (multiples of 10^{12} watts). But this immense flow of energy is difficult to tap for direct human use: wind is diffuse, and it is difficult to harness at the high altitudes and polar latitudes where it is strongest. Only a minute percentage of all precipitation falls in mountain valleys that may be dammed for power generation; the rest lands on the oceans or on watersheds that are not suitable for hydroelectric installations.

Climatic Effects of Land and Water

Both water and land are capable of absorbing and storing heat, but water is considerably more efficient as a storage medium. As a result, large bodies of water tend to moderate the temperatures in their vicinities very strongly, whereas large landmasses exert only a weak effect on air temperatures. This is particularly noticeable where prevailing winds pass over water before reaching land. The West Coast of the United States and Canada, under the influence of the prevailing west winds off the Pacific Ocean, has a much milder climate, cooler in summer and warmer in winter, than does the East Coast, where the same prevailing west winds come off the continental landmass. Water can also transport heat for great distances, as in the case of the warm Atlantic Gulf Stream, which gathers heat in the tropics and carries it northward to soften (and moisten) the weather in western Europe. London, warmed by winds off the Gulf Stream, has little subfreezing weather in winter, whereas Minneapolis, landlocked in the central United States at a somewhat more southerly latitude than London, has considerable snow and protracted periods of bitter cold. Thus latitude alone is not a precise index of climate.

Microclimate

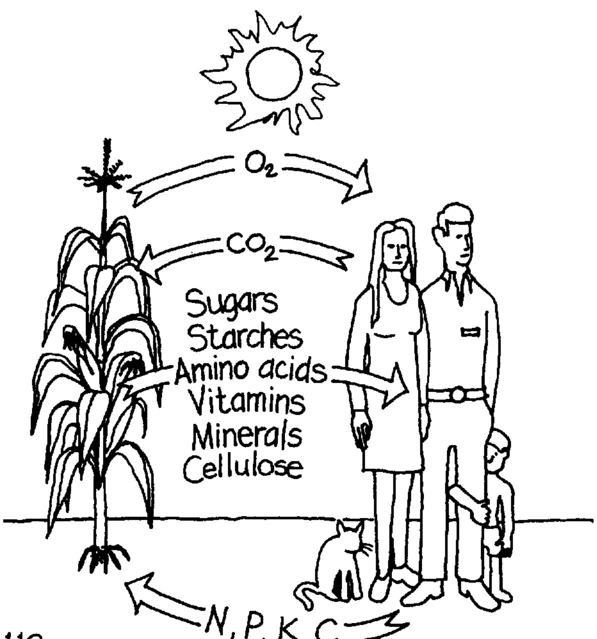
At an individual building site, even more climatic variables may come into play. The apparent movement of the sun across the site is rigidly fixed according to the geographic latitude, but the effect of the sun's radiation varies according to the orientation and steepness of the ground slope, the infrared absorbency of the ground surface, the presence or absence of shading vegetation, and reflected and reradiated solar heat from surrounding buildings and geological features. The air temperature on the site is further affected by such factors as the altitude of the site above sea level, its proximity to bodies of water, the direction of prevailing winds, and the presence of shading vegetation. Fountains, waterfalls, and trees on the site may diffuse enough moisture into the air to raise the local humidity and depress the local air temperature. Local wind patterns are largely dependent on local obstructions to the passage of wind such as forests, trees, buildings, and hills. Plowed ground or dark pavement is warmed by the sun to a higher temperature than are surrounding areas, thereby increasing the radiational heating of nearby surfaces and causing small updrafts of warm air. Topography may have an important role in local convective airflow: a valley may be more protected from wind than a hilltop, but on still, cool nights, rivers of cold air flow down the valley to form pools in low areas while warmer air rises toward the hilltop. Cities, too, affect local weather. The energy released by vehicles and buildings is gradually dissipated in the form of heat to the outdoors, often warming the air by 5 to 10 degrees Fahrenheit (3°–6°C) above that of the surrounding countryside. The artificially warmed buildings and vehicles of large cities often create considerable convective updrafts that can have significant climatic effects on a regional scale.

Other Solar Phenomena

In addition to its thermal effects—those of warming the earth and creating wind and precipitation—the sun also has important nonthermal effects. It provides visible light; it furnishes energy for photosynthesis in plants; and it radiates ultraviolet light.

Daylighting

The role of sunlight in illuminating buildings will be discussed later in detail, but we should note here that direct sunlight is often far too bright for comfortable seeing. Much more useful during the daytime is the visible light scattered by the atmosphere, or the even, restful illumination of a shaded area. If we need light at night, or under dense cloud cover, we must use alternative sources of illumination.



1.10

Photosynthesis

It would be difficult to overemphasize the value to humankind of the photosynthetic reaction in plants. We could not live without it. The human organism cannot create nutrients from sunlight. Plants, however, produce sugars, starches, and proteins from water, carbon dioxide, nitrogen, and soil nutrients through solar-fueled processes. They take carbon dioxide from the air during photosynthesis and give back oxygen as a waste product. (Animals consume oxygen in their metabolic processes and give off carbon dioxide, thus forming the other major link in a self-sustaining environmental chain.) Simultaneously, people and other animals eat whatever plants they are capable of digesting and/or the flesh of other animals that ultimately were nourished by plants. Animal excrement contains nitrogen, phosphorus, potassium, carbon, and other substances that become available to plants through soil and water, and thus food production is perpetuated through other self-sustaining chains (1.10). Even dead plants and animals have a role to play. Their corpses are broken down by other animals and by microorganisms into basic chemical compounds that become once more part of the soil, available to nourish plants and begin life again.

Photosynthesis also produces useful nonfood products such as wood for construction, fibers for the manufacture of fabrics and paper, decorative plants, flowers, ornamental trees and shrubs, and climbing vines. Photosynthesis is responsible for our entire supply of fossil fuels—coal, oil, and gas—which were formed millions of years ago by the effects of geological heat and pressure on large masses of decaying vegetable matter. Except for geothermal energy, nuclear energy, and tides, all our energy sources are solar in origin: not only direct sunlight but also wind energy, water energy, plant energy, and, of course, fossil fuels.

Ultraviolet radiation from the sun is important for its role in photosynthesis, but it has other roles as well. Ultraviolet radiation kills many harmful microorganisms, an effect that is important in purifying the atmosphere and in ridding sunlit surfaces of disease-carrying bacteria. Vitamin D, essential to human nutrition, is formed by the action of ultraviolet light on the skin. On the negative side, ultraviolet rays are responsible for the rapid and soon fatal burning of human skin exposed too long to sunlight and for the high incidence of skin cancer among light-skinned people who are constantly in the sun. Ultraviolet rays also fade dyes in fabrics, decompose many plastics, and contribute to the deterioration of paints, roofing, wood, and other organic building materials. It is because of these negative effects that there is concern about preserving the high-altitude ozone layer that intercepts most ultraviolet radiation before it can reach the earth.

Other Aspects of the Outdoor Environment

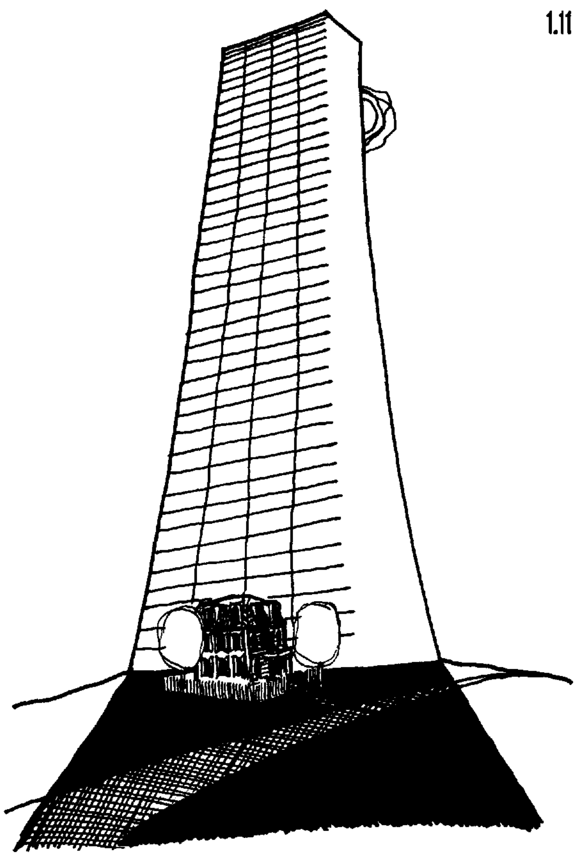
The earth's geology has a great deal to do with the ways in which we build. Many of our building materials, of course, are mineral in origin: earth, stone, concrete, brick, glass, gypsum, asbestos, steel, aluminum, copper, and dozens of others. In many cases the simplest of these can be obtained directly from the building site or from sources in the neighborhood. The subsoil, subsurface water levels, topsoil, and rocks of a site affect the sorts of excavations, foundations, and landscaping that are likely to be undertaken. The contours of the site—its hills, valleys, and slopes—help determine how water will drain during storms, where erosion of soil may occur, where roadways and paths may run without being excessively steep, what areas will be more or less sheltered from wind, what areas will be exposed most favorably to sunlight, where various sorts of plants will grow best, and where and how the buildings will be built. These are exceedingly complex factors, rich in both positive and negative implications for an architect or engineer.

Certain biological factors of the building site are important, too. Microorganisms are universally present in such forms as the bacteria, molds, and fungi that break down dead vegetable and animal matter into soil nutrients. Higher plants such as grasses, weeds, flowers, shrubs, and trees play important roles in trapping precipitation, preventing soil erosion, providing shade, deflecting wind, and other functions already mentioned under the heading of photosynthesis. Insects can affect building design: Biting insects and food-contaminating insects must be excluded from interior spaces. Building-destroying insects such as termites need to be discouraged from attacking the structure. Native reptiles, birds, and mammals also may figure importantly in the planning process. We may want bird songs to filter into the breakfast room, but not the birds themselves. Mice, rats, raccoons, foxes, deer, squirrels, and the neighbor's dog, to name a few, can be nuisance animals in one's building. But a cow, sheep, or horse may be welcome in a barn, and one's own dog, cat, or hamster in a house.

Nearby buildings often affect what we are likely to build. They may shade certain areas of the site, divert the wind in unforeseen ways, upset natural drainage patterns, or cause areas of the site to lack visual or acoustical privacy (1.11). Buildings or remains of buildings erected on the site by previous builders may have to be dealt with, along with their associated driveways, parking areas, walks, gardens, wells, sewage disposal systems, and underground utilities. Bad land-use practices of previous or abutting owners may have caused problems of weeds or soil erosion.

Environmental factors caused by people include air that is polluted with smoke, gases, dust, or chemical particles; noise from

1.11



traffic, industrial processes, a nearby discotheque, or a rowdy family next door; and surface or ground water that is fouled with sewage or chemicals. Sadly, too, a designer must commonly come to terms with the fact that the outdoor environment includes unknown persons who would deface, destroy, or intrude on the building being designed, often before its construction is complete and almost always to the detriment of the building and its occupants.

This, then, for better and for worse, is the outdoor environment, portions of which we may select and modify for human occupancy. It has a warming sun that rises and sets, a procession of seasons, a more-or-less predictable pattern of weather, a unique geology, a varied colony of flora and fauna, and a history of human use and misuse extending through the present and into the future. We must ask ourselves who will occupy and use this environment, what their needs are, and how their needs differ from what this environment can furnish.

Further Reading

David I. Blumenstock. *The Ocean of Air.* New Brunswick, N.J., Rutgers University Press, 1959.

T. F. Gaskell and Martin Morris. *World Climate: The Weather, the Environment and Man.* London, Thames and Hudson, 1979.