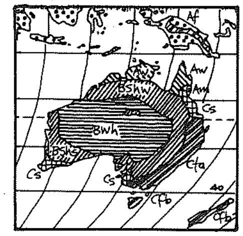


Chapter 5

CLIMATIC FACTORS

If I go out shopping, a glance is sufficient to predict if I am likely to need an umbrella. However, long–term prediction of the weather, over a scale of more than about 10 days is a thankless task. This is because the dynamics of the atmosphere form a system whose behaviour is usually chaotic. The surface of the earth absorbs heat, and so heats the atmosphere from below, and this warm air rises. Heat is lost from the upper atmosphere, and this cooled air falls. A roughly hexagonal cellular array of vortices forms, with the ascending warm air feeding the descending cool air.

(Arun Holden, *New Scientist*, 25 Apr '85.)

The glass is falling hour by hour
The glass will fall forever
But if you break the bloody glass
You won't hold up the weather.
(Louis McNeice.)

5.1
INTRODUCTION

Climatic factors have their most profound effect on the selection of species and technology for site, and are thus the main determinant of the plant, animal, and structural assemblies we can use. There is an intimate interaction between site and local climatic factors, in that slope, valley configuration, proximity to coasts, and altitude all affect the operation of the weather. Such factors as fire and wind effects are site and weather related. It is the local climate that inevitably decides our sector strategies.

Although we will be discussing the individual weather factors that define climate, all these factors interact in a complex and continuously variable fashion. Interactions are made even more unpredictable by:

- longer–term trends triggered by the relative interaction of the orbits of earth, sun, and moon;
- changes included in the gaseous composition of the earth's atmosphere due to vulcanism, industrial pollution, and the activities of agriculture and forestry; and
- extra–terrestrial factors such as meteors, the perturbations in high–level atmospheric jet streams, the oceanic circulation, by fluctuations in the earth's magnetic field, and by solar flares.

There is a general consensus that world climatic variation (the occurrence of extremes) is increasing, so that we can expect to experience successively more floods, droughts, periods of temperature extremes, and longer or very intense periods of wind.

We have separated climatic studies from that of earth surface conditions, and there are climatologists who know little of the effects of forests, industrial pollutants, agriculture, and albedo (albedo is the ratio of light reflected to that received) on the global climate. There is no longer any doubt that our own actions locally greatly affect global and local climate, and that we may be taking unwarranted and lethal risks in further polluting the atmosphere.

Because climatic prediction may forever remain an inexact science, we should always *allow for variability* when designing a site. A basic strategy is to spread the risk of crop failure by a mixture of crop species, varieties, and strategies. This fail–safe system of mixed cropping is basic to regional self–reliance, and departure from such buffering diversity brings the feast–or–famine regime that currently affects world markets.

In house design, the interactions of thermal mass (heat storage) and insulation (buffering for temperature extremes) plus sensible siting permit us to design efficient and safe housing over broad climatic ranges. Strategies such as water storage and windbreak modify extreme effects. Many plant and animal species show very wide climatic tolerances, and local cultivars are developed for almost all important food plants. The variety of food grown in home gardens varies only slightly over a great many situations.

As designers, we are as interested in *extremes* as in means (averages). Such measures as "average rainfall" have very little relevance to specific sites. Of more value are data on seasonal fluctuation, dependability, intensity, and the limits of recorded ranges of any one factor. This will decide the practical limits that need to be included in a design.

People who are called on to design or instruct over wide climatic ranges would do well to read in more general treatments such as Eyre (1971) and James (1941), or in modern biogeographical texts. These treatments deal with world vegetation patterns and climatic factors.

Total site factors related to land configuration will impose specific limits to any design; soil data will also be specific to site. There is, therefore, no substitute in any one design for local observation, anecdotes, detailed maps of local factors, lists of locally successful plant and animal species, and analysis of local soils.

It is obligatory for any designer to study the regional long-term human and agricultural adaptations to climate. Above all, we should avoid introducing temperate (European) techniques and species to tropical and arid lands on any large scale. Aboriginal peoples were never so "simple and primitive" as we have been led to believe by the literature of their invaders. Native agricultural and pastoral management practices are often finely tuned to survival, are sometimes very productive, and above all are independent of outside aid.

5.2
THE CLASSIFICATION OF BROAD CLIMATIC ZONES

Most global climatic classifications are based on precipitation–radiation interactions as formulated by Vladimir Koppen (1918), and subsequently modified and updated by authors such as Trewartha (1954). **Figure 5.1** is from the latter reference. More closely-defined plant lists can be given by reference to the "Life Zone" matrix developed by Holdridge (**Figure 5.2**), which has enabled James Duke and others to annotate plant lists with concise climatic keys. Many plant compendia attach "zones of hardiness" to plant listings, commonly used in the USA. As given in *Hortus Third*, the zones are in **Table 5.1**.

Measures or cut-off points are usually chosen that approximate the limiting boundaries for life forms, and are mainly good approximations of lethal or optimum ranges. The main qualifying factors on the broad classification of climatic factors are:

- special mountain conditions;
- the modifying effects of coasts (and the extremes of continental interiors);
- local energy transfer by winds and oceanic currents; and
- long-term cyclic factors.

Some problems in this area are:

1. Instruments for accurate measurement are expensive, and often specific to a narrow range of the total spectrum of effects.
2. Averages in such areas as precipitation and radiation often refer only to one part of the total spectrum. We have few long-term records of fog precipitation, dew, long-wave radiation, ultraviolet incidence, or gaseous atmospheric composition.
3. We are aware that rain, sun, and wind interact in a dynamic and continuous fashion, so that averages mean little to a plant or animal subject to *the normally changeable effects* that may cover wide ranges of interactive measures.

In this chapter, we are concerned only with the very broad climatic zones (design specifics for each climatic zone are given in later chapters). These have been grouped as follows:

- TROPICAL: no month under 18°C (64°F) mean temperature, and SUBTROPICAL: coolest months above 0°C (32°F) but below 18°C (64°F) mean. In effect, frost-free areas.
- TEMPERATE: coldest months below 0°C (32°F), warmest above 10°C (50°F) mean temperature, to POLAR: warmest month below 10°C (50°F) or in perpetual frost (8°C or less) mean.
- ARID: mean rainfall 50 cm (19.5 inches) or less to DESERT: mean rainfall 25 cm (10 inches) or less. Includes sub-humid, or any area where evaporation exceeds precipitation.

5.3
PATTERNING IN GLOBAL WEATHER SYSTEMS; THE ENGINES OF THE ATMOSPHERE

Dense cold air flows continually off the polar ice caps. This high-pressure or down-draught air spirals out of the polar regions as persistent easterlies which affect high latitudes (60–80°) near the ice-cap themselves. Long spokes of this air curve outward to Latitude 30°.

As the spiral itself is caught up in (and generated by) earth spin, these cold cells of air drive a series of contra-rotating low-pressure cells (turning clockwise in the southern hemisphere and anti-clockwise in the northern). These in turn mesh with rotating spirals of high-pressure air which have risen at the equator, and are falling at Latitudes 15–40°.

The high-pressure mid-latitude cells turn anti-clockwise in the southern hemisphere and clockwise in

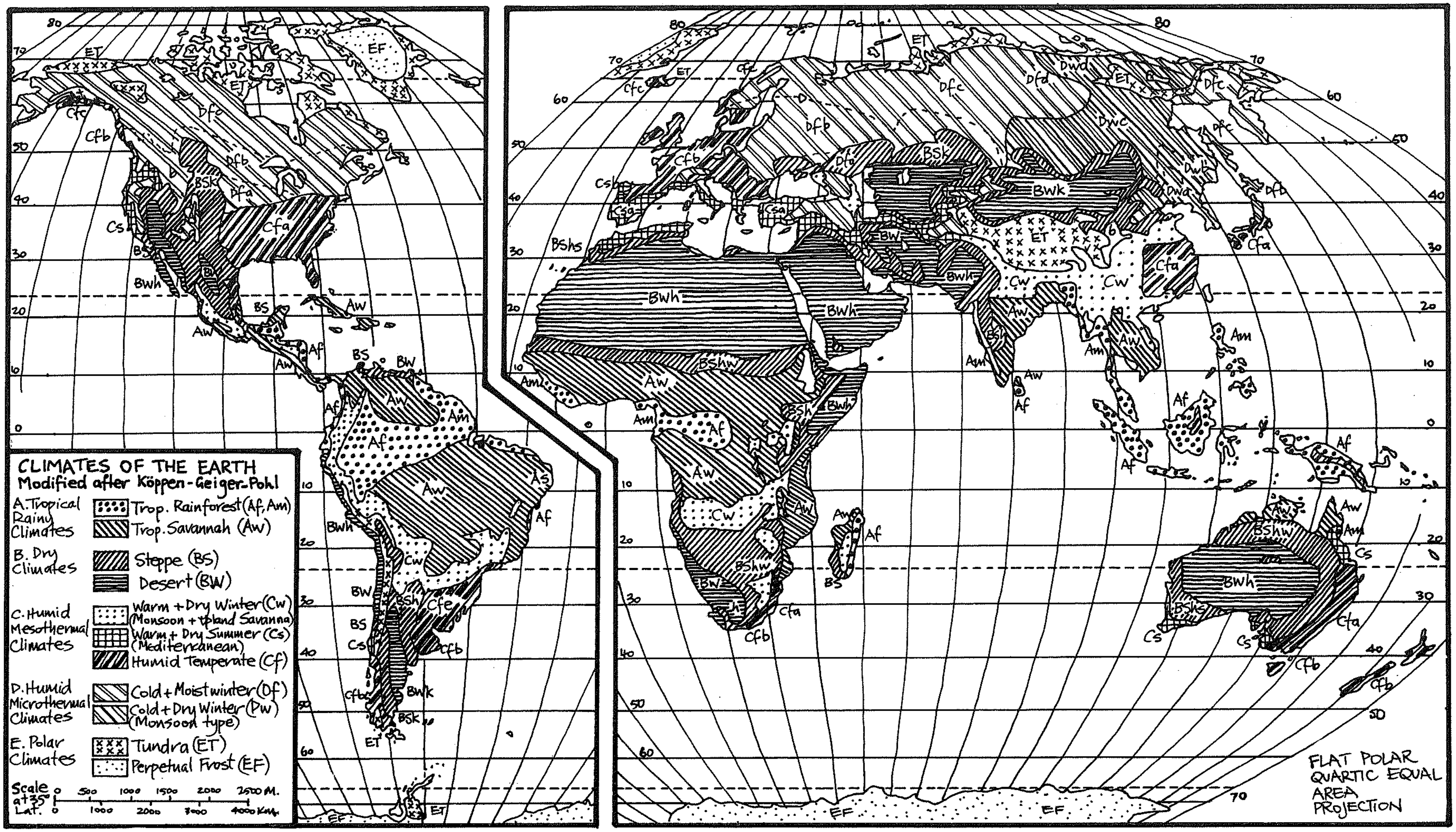
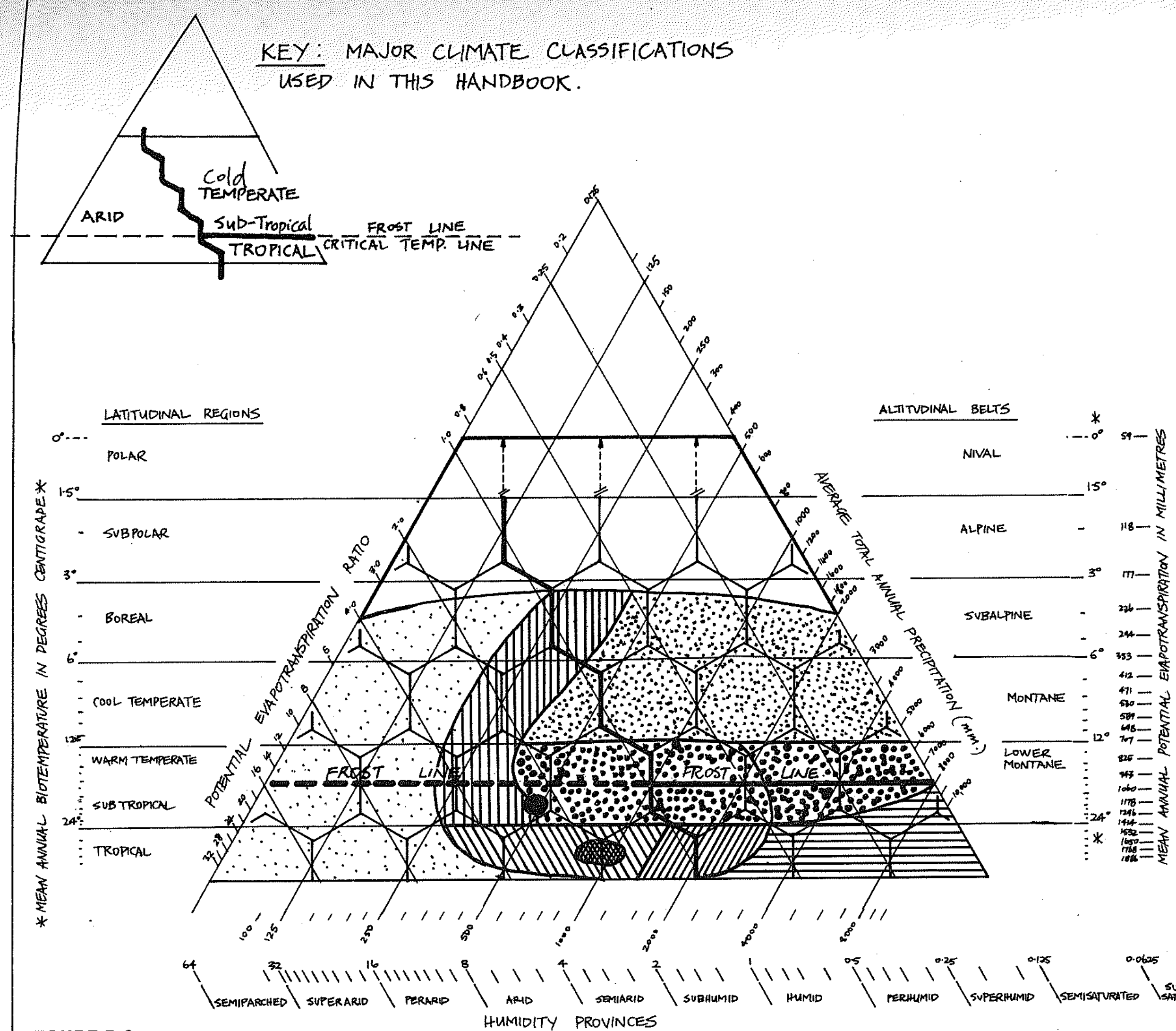


FIGURE 5.1
KOPPEN CLIMATE CLASSIFICATION.
A basic world classification; mionor subdivisions are specified in detailed maps or basic references.



BIOMES	% Area Land Mass	% Plant Mass
Tundra	8	1
Boreal forest	8	16
Chaparral	2.5	1
Temperate grassland	9.5	2
Temeprate forest	7	19
Desert	29	1
Tropical shrub and woodland	10	7
Tropical savannah and grassland	11.5	5
Tropical deciduous forest	4	9
Tropical evergreen forest	10.5	34
TOTAL	100	95
(Human croplands	0.5)	

FIGURE 5.2
HOLDRIDGE LIFE ZONE MATRIX
This analysis suits plant list classifications. The table gives the broad areas dealt with in this book.

TABLE 5.1
HARDINESS ZONES

ZONE	Av. Annual Min. Temp. (°F)	Av. Annual Min. Temp. (°C)	COMMENTS
1	Below -50	Below -45	Arctic tundra
2	-50 to -40	-45 to -40	Cold prairie and conifers
3	-40 to -30	-40 to -34	Conifers and mixed forests
4	-30 to -20	-34 to -29	Cold interiors of continents
5	-20 to -10	-29 to -23	Mixed forests, cool prairies
6	-10 to 0	-23 to -18	Broadleaf and deciduous forests
7	0 to 10	-18 to -12	Broadleaf forests
8	10 to 20	-12 to -7	Arid grasslands, savannah
9	20 to 30	-7 to -1	Semi-arid coasts and basins
10	30 to 40	-1 to 4	Sub-tropical, palms, coasts
11	40 to 50	4 to 10	Tropical forests, deserts
12	over 50	over 10	Equatorial rainforests, monsoon

the northern. Thus from Latitude 50–20°, and in the "roaring forties", about 15–18 alternating high–low pairs of great cells circulate the earth, all of them as smaller spiral systems around the great polar spiral itself (**Figure 5.3**). On westerly coasts, the alternation of cold polar and warm high pressure air arrives at about 10–day intervals, although some great high–pressure cells persist in place, thus blocking westward movement of winds and creating static oceanic conditions that can affect oceanic over-turn, and thus fisheries (e. g. the *el Niño* effect).

These great processions are disturbed and deflected by continents, stubborn high–pressure cells over cool land masses, and the relative intensity of the air cells, so that irregular cold–warm fronts arrive at any one site. Just as polar air is sometimes drawn strongly towards the equator in the lows, so warm tropical air masses are entrained in the outer circulation of the highs and bring heavy warm rains towards the poles. High level jetstreams may speed up or block this procession and the jetstream itself may also break up under stresses caused by shear.

The disturbances and impedences in the system cause cold fronts to pile up against each other and deflect polewards at high–pressure cells, and a sequence of warm– and cold–front rains (the cyclonic or spiral rains) of earth results.

All these wind belts shift north or south with the sun annually, and to some slower extent as a result of the 18.6–year moon cycle, so that periods of drought and excessive rain can result. The system appears chaotic, and subject only to short–term prediction, but of late we are learning to assess some of the effects of the long–term cycles.

The great spiral circulation of the south polar regions is shown in **Figure 5.3**. About 12–18 cold fronts (cloud bands) circle from west to east around the poles, arriving as "cyclonic fronts" every 10 or so days on coasts in that region. They affect areas up to 30° south, with four or so large fronts continuous with (and probably driving) cloud up to 10° south or north latitude, mostly along the western margins of South America, Africa, and the south Atlantic. It is now clear that it is the *oceanic* circulation that drives the air masses, rather than the opposite.

The fronts are dragged in a curve to the west as the earth spins to the east. Each cloud front is a result of the meeting of cold polar and warm sub–polar air masses or high–pressure cells. The low–pressure areas rotate clockwise, the highs anti–clockwise in a series of cog–like spirals or tori that travel every 3–4 months around the poles. Rotation is in the opposite sense in the northern hemisphere. It is the cold, dense, dry polar air sweeping off the ice–caps, and the hot rising air of the equatorial calms which drives these great wheels; clear–air (descending) intrusions are of hot–dry and cold–dry continental air (Australia, Africa) or air descending from the equatorial (rising) congruence (**Figure 5.4**).

In the next sections of this chapter, I will be discussing CLIMATIC FACTORS under parts, as below:

- Precipitation (rain, fog, dew, evaporation–**5.4**);
- Radiation (light, heat, frost, solar input–**5.5**);
- Winds (normal winds, hurricanes and tornadoes - **5.6**);
- Landscape effects (altitude, valleys, slopes–**5.7**); and
- Latitude–altitude factors (**5.8**).

5.4
PRECIPITATION

There are two basic inputs to precipitation: that of rainfall, snow, and hail (WATER FALLING from the clouds), and that of CONDENSATION (water condensed or trapped from sometimes clear air or fogs by cool surfaces). Although the latter may be of critical importance on seaward slopes and at higher altitudes (cloud forests), the only reliable and widespread measures we possess are of "rainfall". World rainfall averages about 86 cm (34 inches). While we may take 50 cm (20 inches) of rainfall or less as semi–arid, and 25 cm (10 inches) or less as arid and desert, we can locally experience seasonal or relative aridity due to long–term cycles and weather effects caused by periodic fluctuations in jetstreams or oceanic currents *in any climate.* Longer periods of increased aridity can also be caused by deforestation on a broad or local scale.

It is because of the potential for changes in precipitation that we give so much space in later chapters to water storage strategies and the conservation of water. Water promises to be the main limiting factor for survival and growth, and the major future expense of food gardens and agriculture. Thus, any strategy we can adopt to generate, conserve, or store water is critical to our design approach. Any gardener knows that climatic averages are at best a very general guide to precipitation effects in the garden or orchard. It is a much safer strategy to see to it that both the species chosen and water strategies developed ensure some yield in "drier than usual" conditions. After all, a fish population out of water for an hour is as dead as if a year–long drought were in effect.

Our annual gardens and crops are also susceptible to short–term changes in available water. People live, and garden, in average annual rainfalls of 10 cm (4 inches) or less, and they manage to both exist and produce crops. Exotic (non–local) water enters dry regions as rivers and underground aquifers, and this enables us to make judicious use of that water and to implement a great variety of local strategies to cope with the lack of actual rainfall.

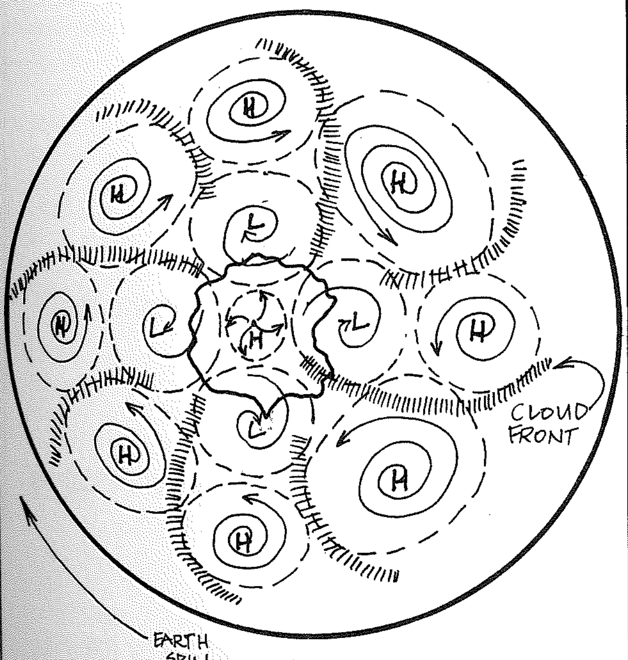


FIGURE 5.3
SPIRAL AIR CELLS AROUND THE SOUTH POLE.
Cloud bands (shaded) bring rains on the E–NE sides of high pressure, and the S side of low pressure cells. Earth spin produces a drag effect. This pattern affects climate to 25° Latitude, when cyclones feed the system.

Rainfall averages are best used as broad indicators rather than as definable limiting factors. Of far more use to us is the expected DISTRIBUTION of rainfall (including extremes such as 100–year flood records) and data on the INTENSITY of rains, as these factors are a limiting influence on the size of road culverts, dam spillways, and the storage capacity needed to see us over dry periods. Flooding histories of sites and districts often indicate the real limits to the placement of plant systems, fences, and buildings, so that attention to flood records avoids future costs and disappointment If flood data is omitted, life itself can be at risk in intense periods of rain.

As precipitation rises, available light decreases. Thus, in extremely cloudy industrial or fog–bound humid climates, *light* becomes the limiting factor for some plants to ripen or even flower. At the dry end of the rainfall spectrum (as we reach 50 cm or 20 inches mean rainfall) sun is plentiful and *evaporation in excess of precipitation* becomes the limiting factor. That factor determines our arid–land storage strategies, just as the depth of seasonally frozen soils and ice cover determines water reticulation strategies in cold climates.

Rainfall is conveniently distinguished by the processes causing rain as:

- OROGRAPHIC: the cooling of air as it rises over mountains or hills.
- CYCLONIC or FRONTAL: the over–riding of cool and warm air masses of the polar circulation.
- CONVECTIONAL: columns of hot air rising from deserts or oceans into cooler air.

Apart from rain, we have dew and fog. DEW is a common result of clear nights, rapid radiation loss, and a moist air mass over coasts and hills. It occurs more frequently in clear–sky deserts than in cloudy areas, and a slight wind speed (1–5 km/h) assists the quantity deposited. Both still air and strong winds reduce dewfall. Intensity of deposition is greatest 3–100 cm above ground level; the highest deposition due to areas of dry ground, the lower due to wet earth, which chills less quickly.

Not to be confused with dew (a radiation heat loss effect from earth with *clear* night skies) is the moisture found on leaves above warm damp ground on *cloudy* nights. This is either GUTTATION (water exuded from the leaves) or DISTILLATION from rising ground vapour; it represents no net gain to total precipitation. The waters of guttation cling to the tips of leaves, dew to the whole leaf area.

Only in deserts is the 4–5 cm (1–2 inches) of dew per year of any significance in precipitation. Dew in deserts can be regarded as an accessory to, rather than a replacement for, trickle irrigation. Dew may be captured by building piles of *loosely–stacked* stones, where low night winds cool rock surfaces and dew can accumulate to dampen the ground below. In the Negev desert and other dry areas, some plants are associated only with these dew condensers. Each mound of stones may suffice to water one tree (**Figure 5.5**). Very large radiation traps, such as those on Lanzarote in the Canary Islands (**Figure 5.6**) may grow one grape vine in each hole.

The most efficient dew–collectors are free–standing shrubs of about 1–2 m (3–6 feet) in height. Groups or solid stands of plants and grasses do less well in trapping dew, and this may help to explain the discrete spacing of desert plants, where perhaps 40% more dew is trapped on scattered shrubs than would be caught in still air, or on closed vegetation canopies.

It is possible to erect metallic mesh fences 1 m (3 feet) or so high, and to use these as initial condensers in deserts, growing shrubs along the fence drip–line, and moving the fence on after these plants are established. In Morocco such fences are proposed for deforested coastal areas.

FOG forms where warm water or the vapour of warm rain evaporates into cool air, or where cold ground chills an airstream and condenses the moisture. Chang (1968) concisely differentiates between:

1. RADIATION GROUND FOG: where, on clear nights, hollows and plateaus cool rapidly and fog forms, often in much the same pattern as the frosts of winter.
2. ADVECTION FOG: where cold offshore currents condense the moisture in warm sea airstreams. These are the coastal and offshore fogs that plague many coasts such as that of Newfoundland and parts of northwest Europe.
3. UPSLOPE OR OROGRAPHIC FOG: where warm, humid airstreams are carried up hill slopes, and condense as the air cools.

Unlike dew, fogs can provide a great quantity of moisture. Chang gives figures of 329 cm (128 inches) for

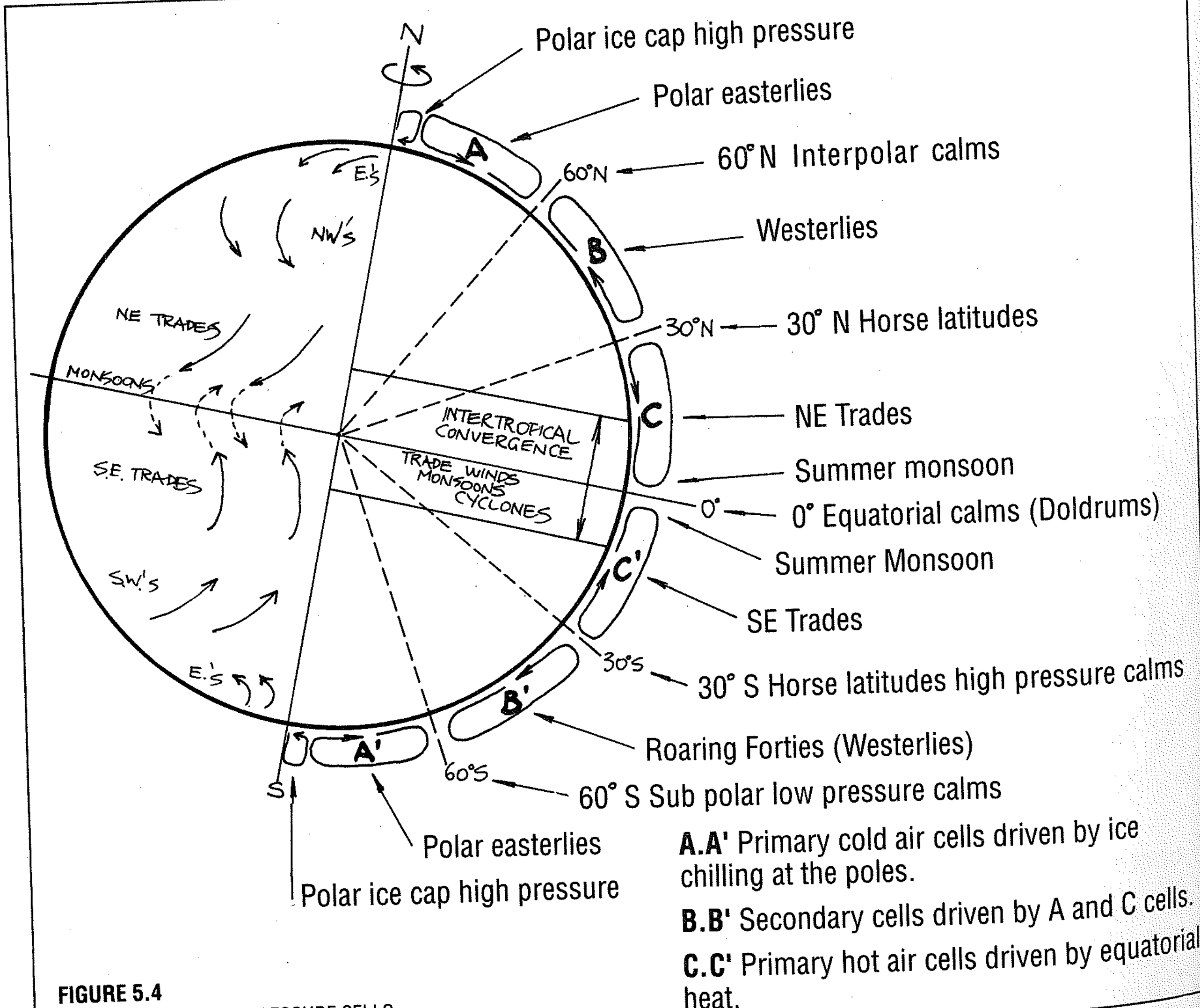


FIGURE 5.4
WIND DIRECTION AND PRESSURE CELLS.

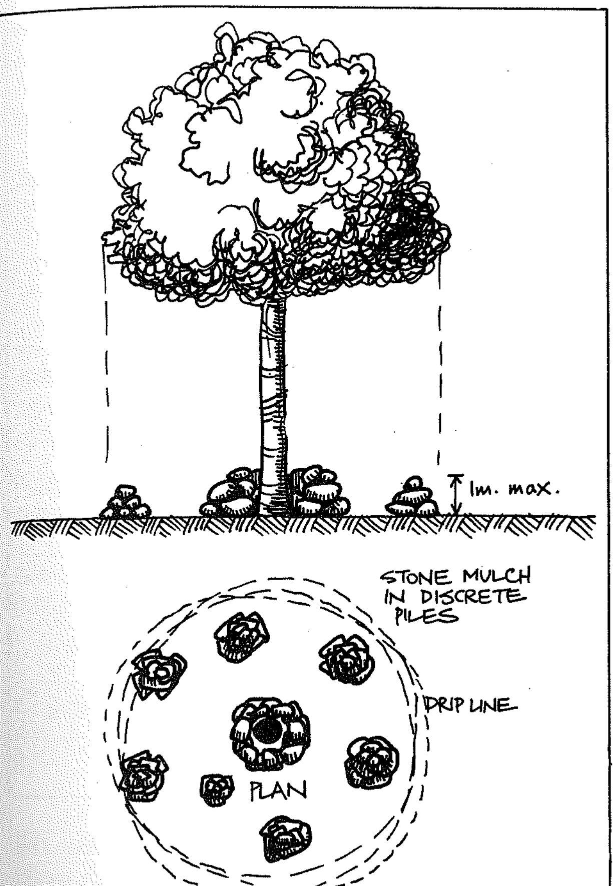


FIGURE 5.5
STONE MULCH UNDER TREE (CONDENSATION TRAP).
Loose piles of stone of less than 1 m high condense moisture from night air movement. Free air flow is permitted between stone piles.

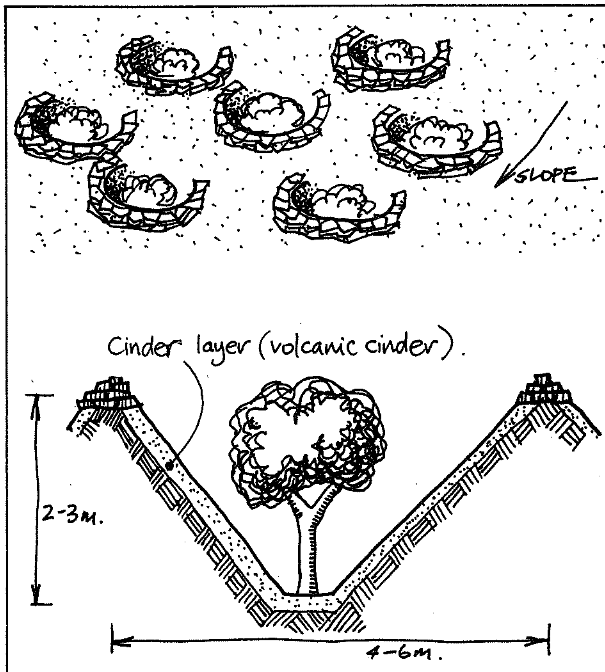


FIGURE 5.6
CONDENSATION TRAP OF LANZAROTE.
Cold air sinks in these cinder–covered pits, condenses on cinder.

Table Mountain, South Africa, and 127 cm (50 inches) for Lanai (Hawaii) from fog drip alone. In such areas, even field crops may thrive without irrigation. Typically, bare rock and new soil surfaces are colonised with lichens and mosses on sea–facing slopes, while rainforest develops on richer soils. Much of New Zealand experiences upslope fog precipitation, and unless burnt or cleared to tussock grasslands, dense forests will develop; the irregular canopy of such forests are excellent fog condensers. Even with no visible fog, trees will condense considerable moisture on sea–facing slopes with night winds moving in off warm seas over the land, and encountering the cool leaf laminae of forests.

In the very humid air of fog forests, giant trees may accommodate so much moisture, and evapotranspiration is so ineffective if fogs and still air persist, that more large limbs fall in still air than in conditions of high winds (which tend to snap *dry* branches rather than living limbs). It is an eerie experience, after a few days of quiet fogs, to hear a sudden "thump!" of trees in the quiet forests. Almost permanent condensation fogs clothe the tops of high oceanic islands, and hanging mosses and epiphytes rapidly develop there, as they do at the base of waterfalls, for the same reasons (free moisture particles in the air).

5.5
RADIATION

SOLAR RADIATION

Incoming global radiation has two components: DIRECT SOLAR RADIATION penetrating the atmosphere from the sun, and DIFFUSE SKY RADIATION. The latter is a significant component at high latitudes (38° or more) where it may be up to 30% of the total incoming energy. Near the poles, such diffuse radiation approaches 100% of energy. We have reliable measures only of direct solar radiation, as few stations measure the diffuse radiation which occurs whenever we have cloud, fog, or overcast skies.

Light and heat are measured in WAVELENGTHS, each set of which have specific properties. We need to understand the basics of such radiation to design homes, space heaters, and plant systems; to choose sites for settlement; and to select plant species for sites. **Table 5.2** helps to explain the effects of differing wavelengths.

A minor component of terrestrial radiation at the earth's surface is emitted as heat from the cooling of the earth itself. The greater part of the energy that affects us in everyday life is that of radiation incoming from the sun.

Of the incoming or short–wave radiation (taken to be 100% at the outer boundary of the atmosphere):

- 50% never reaches the earth directly, but is scattered in the gases, dust, and clouds of the atmosphere itself.

TABLE 5.2
SOME WAVELENGTHS AND EFFECTS

WAVELENGTH (Millimicrons)	**DESCRIPTION**	**COMMENT**
0-400	Actinic or Ultra Violet: only 1.5-2% reaches the Earth, most being absorbed by the ozone layer.	Causes sunburn, skin cancers. May be increasing due to ozone layer destruction.
400-626	Visible light (white light) composed of:	The rainbow colours visible as differentiaited by water vapour or a prism. About 41% of radiation reaching Earth.
400-435	Violet	
436-490	Blue	
491-574	Green	
575-595	Yellow	
595-626	Orange	
627-5,000	Heat (long wave radiation) and radio waves	
627-750	Red	Emitted by bodies heated by combustion, or those which have absorbed short wavelengths. About 50% of radiation reaching Earth.
751-3,000	Far red	
3,001+	Infra red	

Of this 50%:

— half is reflected back into space from the upper layers of cloud and dust.

— half converts (by absorption) into long–wave or heat wavelengths, within the dust and clouds that act as a sort of insulation blanket for earth.

• 50% reaches the earth as direct radiation, mostly falling on the oceans. Of this 50%:

— 6%, a minor amount, is again lost as reflection to space.

— 94% is absorbed by the sea, earth, and lower atmosphere and re–emitted as heat or converted to growth.

Of the outgoing, or terrestrial, radiation (absorbed solar radiation and earth heat, including the added heat released by biological and industrial processes and condensation), the heat that drives atmospheric circulation:

67% is re–radiated to space, and lost as heat. In the atmosphere, therefore, most heat is from this re–radiated heat derived from the surface of the earth.

• 29% is released from condensing water as sensible heat.

Ozone in the upper atmosphere absorbs much of the ultraviolet light, which is damaging to life forms. Carbon dioxide, now 3–4% of the atmosphere, is expected to rise to 6%, and cause a 3°C (5.5°F) heating of the earth by the year 2060. This process appears to be already taking effect on world climate as a warming trend, and will cause sea level changes.

The effect of radiation on plants is different for various wavelengths, as in **Table 5.3**.

Other sources of light for the earth are the moon (by reflection of sunlight) and star light. Although weak, these sources do affect plant growth, and even fairly low levels of artificial light affects animal and plant breeding. The major effects of radiation overall are:

• PHOTOSYNTHESIS in plants, the basis of all life on earth.

• TEMPERATURE effects on living and inorganic substances, much used in house design.

• FLOWERING or GERMINATION effects in plants, of basic importance to the spread of specific plant groups; this includes the day–length effect.

Plants actively adjust to light levels by a variety of strategies to achieve some moderate photosynthetic efficiency. They may keep the balance between heat and light energies by adopting solar ranges to suit the specific environment (silvery or shiny leaves where heat radiation is high; red leaves where more of the green spectrum is absorbed and less heat needed). Leaves may turn edge–on when light and heat levels get too high, or greatly enlarge their surface area under a shady canopy. Trees have larger leaves at the lower layers.

COLOUR

When we look at any object, we see it by receiving the wavelengths of the light it REFLECTS or screens out. Thus, many plants reflect green/blue wavelengths, while flowers reflect a wider spectrum of light, becoming conspicuous in the landscape. About 10% of light penetrates or is transmitted by foliage, although the canopy of rainforests in very humid areas (tropical or temperate) may permit only 0.01% of light to pass through to the forest floor. Absorbed light, as heat, is re–radiated or used in growth.

In addition to leaf colour, plants have bark surfaces ranging from almost white to almost black, the latter good absorbers and heat radiators, the former good reflectors. Leaf surfaces may vary from hard and shiny to soft, rough, and hairy. Typically, waxy leaf surfaces are found in coastal or cold areas, and in some understory plants, while woolly leaf surfaces are found in deserts and at high altitudes. The waxiness often gives a greater reflection of light regardless of colour, while dark or rough surfaces absorb light, so that dark evergreen trees become good radiators of heat.

All of these factors (colour, reflection, heat radiation) are of as much use in conscious design as they are in nature, and can be built in to gardens or fields as aids to microclimatic enhancement.

ALBEDO AND ABSORPTION

The albedo (the reflected light value) of plants and natural surfaces determines how they behave with respect to incoming radiation. The light *reflected* goes back into the atmosphere, or is absorbed by nearby surfaces and by structures such as greenhouses. The light *absorbed* is converted into long–wave radiation, and is re–emitted as heat (**Figure 5.10**). Soils and similar dense materials normally absorb heat from

TABLE 5.3
THE EFFECTS OF RADIATION ON PLANTS IS DIFFERENT FOR VARIOUS WAVELENGTHS.

WAVELENGTH (Millimicrons)	**DESCRIPTION**	**EFFECT**
0-280 (UV)	UV or actinic	Kills plants and animals. Germicidal.
281-315 (UV)	UV or actinic	Detrimental to plants, growth.
316-400	Violet	Plants shortened, leaves thickened.
410-510	Violet-Green	Strong absorption and growth in plants. Effective photosynthesis. Transmitted by fibreglass, several plastics.
511-610	Green-Orange	Low growth and photosynthetic effect.
611-720	Orange-Red	Strong absorption and photosynthesis, photoperiodic behaviour=day length effect.
71-1,000	Red-Far Red	Plants elongate, important for seed germination, flowering, photoperiodism, fruit colouration.
1,000+	Infra Red	Absorbed and transpired into heat by plants; no strong growth effects.

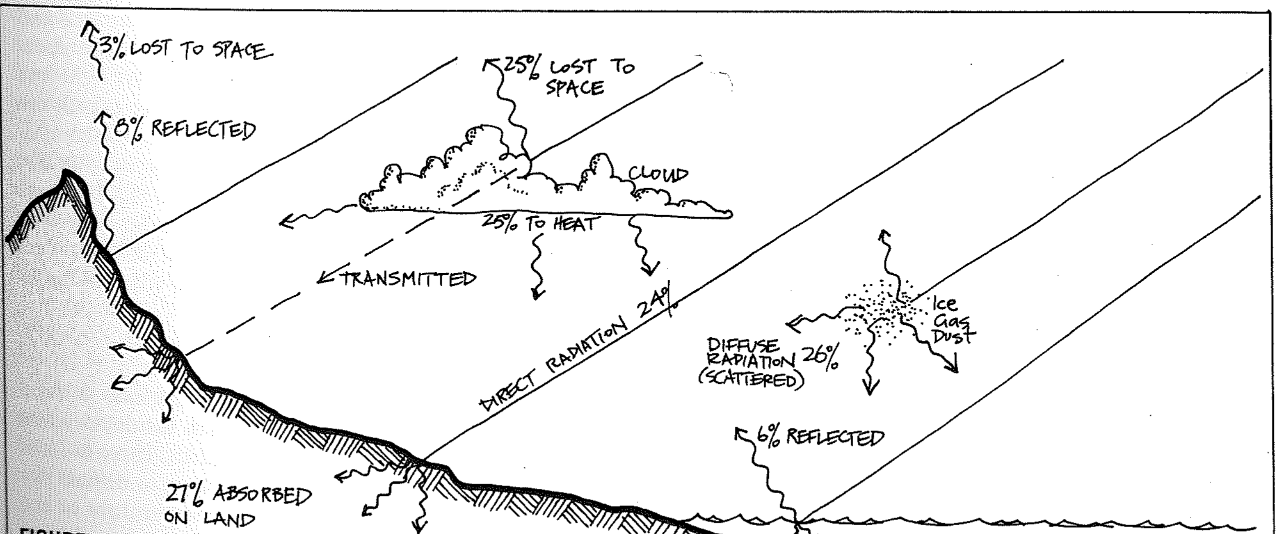


FIGURE 5.7
INCOMING SHORT–WAVE RADIATION.
The fate of radiation in differing media.

daytime radiation to a depth of 51 cm (20 inches) or so. As this takes time, the build–up of soil heat lags a few hours behind the hourly temperatures. Re–radiation also takes time, so that such absorbing surfaces lose heat slowly, lagging behind air temperatures. Thus we have our lowest soil temperatures just after dawn. The radiation loss at night produces frost in conditions of still air [in hollows, on flats, and in large clearings of 9–30 m (30–100 feet) across or more in forests]. Some frost (ADVECTION frost) flows as cold air down hill slopes and valleys to pool in flat areas. Frost forms rapidly on high plateaus. Dense autumn fogs often indicate the extent of winter frosts, and are clearly seen from high vantage points.

As designers, we use water surfaces, reflectors, and specific vegetational assemblies for forest edges. **Table 5.4** gives an indication of the value of diffuse reflectors, as **albedo**. A perfect reflector refuses 100% of light (mirrors); a perfect absorber is a BLACK BODY that absorbs all light and converts it to heat.

The fate of incoming waves encountering an object or substance is either:

- REFLECTED: turned away almost unchanged, as light off a flat mirror or off a white wall.
- REFRACTED: sharply bent or curved, as is light in water, images in curved glass, or sea waves around a headland.
- ABSORBED: soaked in, as when a black object soaks up light. This changes the wavelength (light to *heat* or short to *long* wavelength). All absorbed light is emitted as heat.
- TRANSMITTED: passed through the object.

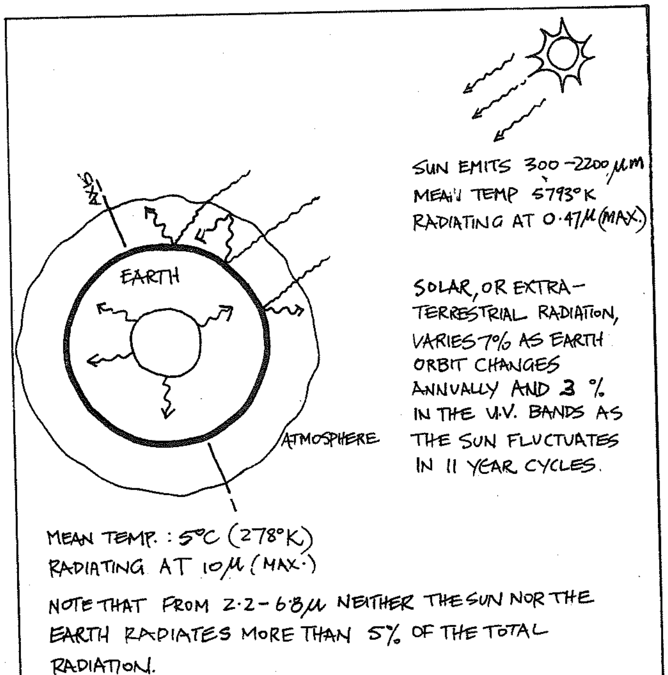


FIGURE 5.8
GLOBAL RADIATION.
Most heat is trapped by moisture, dust, or gases in the atmosphere; a little is emitted by the Earth itself.

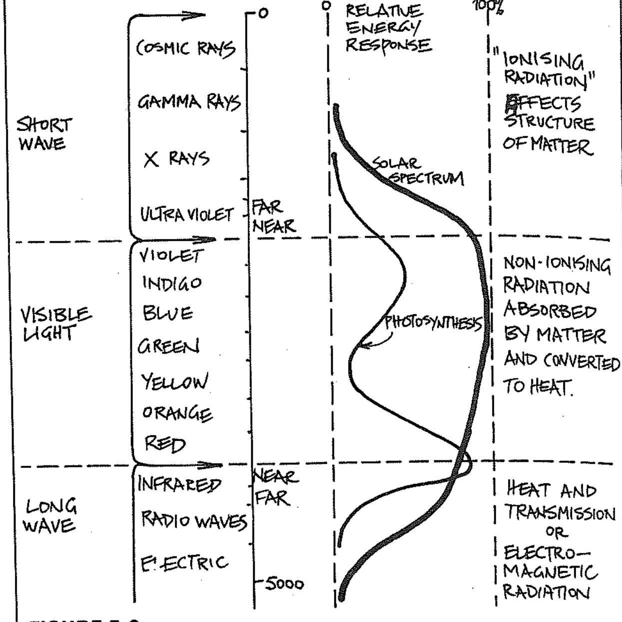


FIGURE 5.9
THE SUNLIGHT SPECTRUM (0–5,000 A)
Plant growth (photosynthesis) relies on two narrow bands of light, is damaged by extreme ultraviolet or heat wavelengths.

Different substances pass on, or are "transparent" to, different wavelengths due to their molecular structure.

Thus it is by our choice of the materials, colours, or shapes of fabricated or natural components that we manipulate the energy on a site. We can redirect, convert, or pass on incoming energy. The subject of radiation ties in with areas of technology as much as with natural systems, and this section will therefore serve for both areas of effect.

The earth itself acts like a "black body", accepting the *short* wavelengths from the sun, and emitting after absorption the *long* wavelengths from the surface and atmosphere. **Table 5.2** deals mainly with the short wavelengths, as they are those coming in as light and heat from the sun. The long wavelengths we experience are those re–radiated to earth from the atmosphere, or emitted by the hot core of earth. Curiously, snow is also a black body in terms of heat *radiation*. Black objects such as crows or charcoal can become effective *reflectors* if their shiny surfaces are adjusted to reflect radiation (a crow is black only at certain angles to incoming light).

HEAT (Longwave radiation)
It is difficult to store heat for long periods in field conditions, although it can be done in insulated water masses or solids such as stone and earth. There is some heat input every day that the sun shines or diffuse sky light reaches the earth. The mean temperature of the earth is 5°C (41°F), of the air at or near ground level 14°C (57°F), and of the outer layers of the atmosphere –50° to –80°C (–90° to –144°F). Normally, we lose about 1°C for every 100 m increase in altitude (3°F per 1000

TABLE 5.4
SOME ALBEDOS

	Reflected (%)	Absorbed (%)
"The perfect reflector"	100	0
White, smooth paint	96	4
Clean fresh snow	75-95	5-25
White gravel	50-93	7-50
Dense white clouds	60-90	10-40
Calm water (Sun 15° elevation)	50-80	20-50
Adapted desert shrubs	30-38	62-70
Sand dunes	30-40	60-70
Sandy soils	15-40	60-85
Dry hay	20-40	60-80
Wood edges	5-40	60-95
High sun, rough water	8-15	75-92
Young oaks	18	82
Young pines	14	86
Dark soils	7-10	90-93
Fir forest	10	90
"The perfect black body"	0	100

feet). In most conditions we experience a reduction in temperature with increasing altitude, but in many valleys, or on plains surrounded by mountains, cool air from the hills or cold air generated by rapid radiation loss from soils creates a condition where layers of dense cooler air are trapped below warmer air, and we have a TEMPERATURE INVERSION. It is in such conditions that fog, smog, and pollution can build up over cities lying in valleys or plains, where wind effect is slight. Such sites must be carefully analysed for potential pollutants.

As in the case of precipitation, it is advisable to research temperature extremes for site. Poultry (and many wild birds) do not survive temperatures greatly in excess of 43°C (109°F), nor do plants survive transplant shock from nursery stock when soil temperatures exceed 36°C (97°F), whether in deserts or in compost piles. Many plants are frost–affected at or below 0°C (32°F), and below this, sustained periods of lower temperatures will eliminate hardier plant species (even if well–established). Thus, the very widespread and sometimes economically disastrous black frosts that affect whole regions should be noted by site designers as much as flood periodicity. Livelihoods should not depend on broadscale plantings of frost-susceptible crops in these situations.

CONVECTION LOOPS AND THERMOSIPHONS

For building and garden designs, we should be aware of just how heat is stored and transmitted. First, we need to distinguish between lowgrade heat transmitted by CONVECTION, or the passage of air and water over slightly heated surfaces. It is this effect which operates in valley climates, and which creates valley winds. Cool air is heavier (more dense) than heated air; the same factor holds true for water or liquids, and other gases (and fluid flow generally).

Thus, providing heated air or water is contained in pipes or ducts, a closed loop circulation can be set up by applying heat to the lower part of that loop, providing that a least rise or height difference of 40 cm (about 18 inches) is built in to the loop; any greater height is of course also effective in producing a **thermosiphon** effect (**Figure 5.11**). This is the effect used in refrigerators driven by flames or heat sources.

In the atmosphere, columns of heated air over land ascend as an "Overbeck jet" (**Figure 4.13**), and at the top of this column, condensation and rain may occur as the air is cooled in the upper atmosphere. Such convectional rains are responsible for the mosaic of rainfall that patterns the deserts.

Convection loops will *not* occur in closed rooms, where hot air [at 8–10°C (1518°F) higher temperture] sits in a quiet or stratified layer below ceilings. As air is difficult to heat, and stores little heat, air convection is not an efficient way to heat building interiors, although it is the main "engine" of atmospheric circulation in the global sense.

Thermosiphons are useful in transferring heat from solar ponds or flat plate collectors to home radiators or hot water tanks; we should, wherever possible, site these heat collectors 0.5 m (1.6 feet) below the storage or use points so that they are self–regulated thermo-

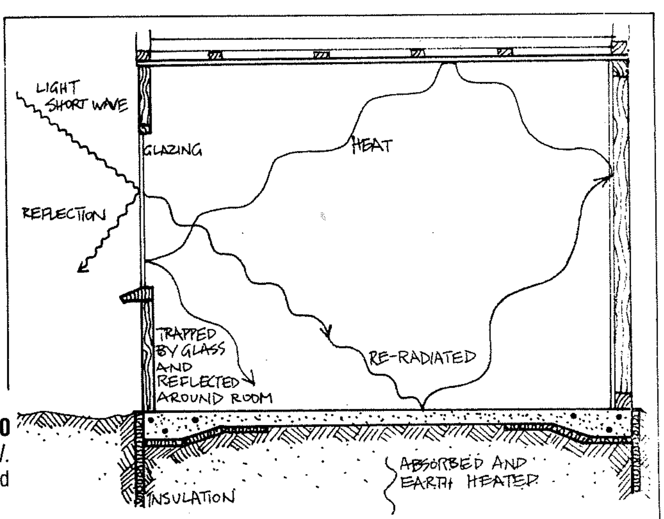


FIGURE 5.10
EFFECT OF LIGHT PASSING THROUGH A WINDOW.
Glass is less permeable to long (heat) radiation, thus it "traps" radiated heat but transmits short–wave light.

siphons.

HEAT TRANSFER

Heat flows from warmer to colder bodies, and just as warm air transfers heat to cool solid bodies by day, so warm bodies can heat large volumes of air at night. Bodies that are heated expand, decrease in density, and (where there is freedom to move) heated air or water rises as CONVECTION CURRENTS.

The common heat unit is that needed to raise one gram of water from 14.5°C to 15°C. In terms of incoming radiation, gram calories per square centimetre ($g/cal/m^2$) are termed LANGLEYS; the sun provides about 2 Langleys/minute to the outer atmosphere.

The quantity of heat received on earth is greatly affected by:

- latitude and season (the depth of atmosphere);
- the angle of slopes (which in turn affects reflection and absorption); and
- the amount of ice, water vapour, dust, or cloud in the air above,

This means that the Langleys received at ground level vary widely due to combinations of these factors. Nevertheless, most homes receive enough sunlight on their sun–facing areas to heat the water and space of the house, if we arrange to capture this heat and store it.

However, even when the sun is directly overhead on a clear day, only 22% of the radiant energy penetrates the atmosphere (1 atmosphere depth). In polar areas, where the slanting sun at 5° elevation passes obliquely through at a distance of 11 atmospheres, as little as 1% of the incoming energy is received! Slope has similar profound effects, so that slopes facing towards the poles receive even less energy from radiation.

It follows that siting houses on sun–facing slopes in the THERMAL BELT is a critical energy–conservation strategy in all but tropical climates, when siting in shade or in cooling coastal windstreams is preferred. Sun–facing slopes not only absorb more heat, but drain off cold air at night; they lie below the chilly hilltops, and above the cold night air of valleys and plains (**Figure 5.12**).

In hill country and mountains, these thermal belts may lie at 1000–5000 m. (3,280–16,400 feet), and on lower hill slopes at 100–200 m. (330–650 feet), whereas in hot deserts the frost levels may only reach to 10–15 m. (33–49 feet) up the slopes of mesas. Each situation needs specific information, which we can gain from local anecdotes, the observation of existing plants, or trial plantings of frost–susceptible species.

Winds travelling from warmer to cooler regions, or the opposite, bring ADVECTED (exotic, or out of area) warmth and cold to local regions. Thus we speak of advection fogs where these come inshore from coasts, and advection frosts when cold air flows down mountain slopes to pool in hollows.

The invasion of cool areas by warm advected air causes moisture condensation, which is critical to precipitation in forests, but a nuisance in enclosed buildings. Thus, we should attempt to bring only *dry* warm air into wooden houses, or provide ways to direct condensation moisture to the house exterior.

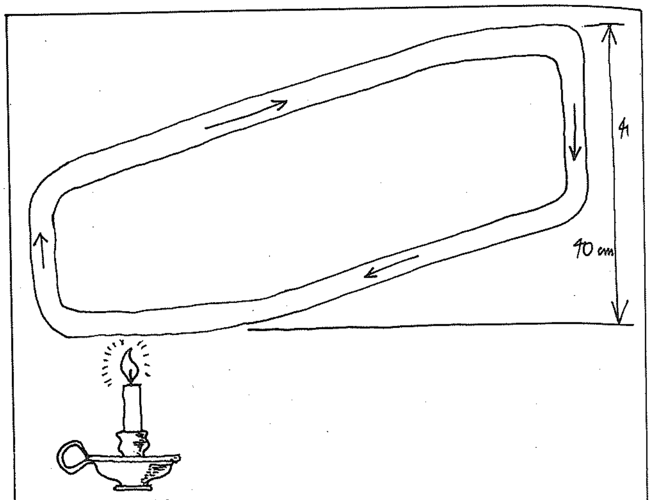
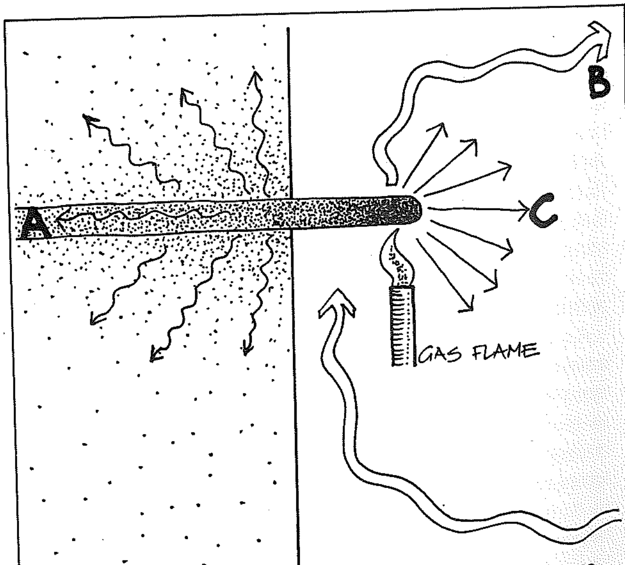


FIGURE 5.11
CONVECTION LOOP OR THERMOSIPHON.
Heat applied at "A" in a closed loop causes fluid flow in the loop if the top of the loop is 40 cm or more above the heated section of the loop.

Intermediate grades of heat can be transmitted by CONDUCTION, as when solids are in contact. It is in this way that we heat an entire floor or wall by heating it in one place, and this is the basis of the efficiency of the slab–floored house, where the floor is previously insulated from surrounding earth. In open (uninsulated) systems, conduction effects are local, as



A HEATED BAR EMBEDDED IN CONCRETE DEMONSTRATES HOW HEAT DIFFUSES TO COLDER AREAS.
A "Low grade" heat is conducted from solid to solid or fluid to fluid by contact. Insulation is effective in trapping such heat.
B "Medium grade heat " is convected" by the movements of fluids or gases, as in air, wind, or water. Draught–proofing conserves this heat. Heated fluids rise.
C "High grade heat" travels by straight–line radiation in all directions and can only be conserved by reflective (dust–free) surfaces or mirrors. This is how the sun heats the Earth.

heat is fairly rapidly radiated from solids or soil surfaces. Pipes buried in hot solid masses have heat conducted to their contents, or hot water pipes conduct heat to slab floors in which they are buried; such heating is most efficient in homes.

Intense heat trapped in solids and liquids is RADIATED, which is the effect transmitted across space by the sun. Radiant heaters affect air temperature very little, but radiation heats other solids and liquids (like our bodies) or dust in the air. Thus, we can keep very warm even in a draughty or cool room by the use of radiant electric, gas-fire, or wood-heated massive stoves; these are very efficient space heaters. As radiation crosses space, and is nondirectional, focused radiation can produce very intense heat locally.

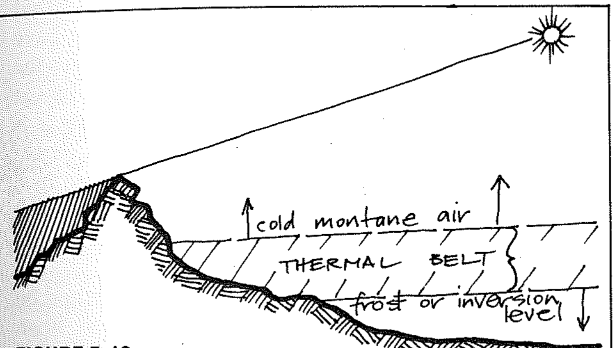


FIGURE 5.12
THERMAL BELT.
A midslope, moderate zone suited to gardens and housing; the shaded side of the hills accentuate cold, low evaporation, and suit very different species.

PLANTS AS HEATERS

Most or all Arum lilies, and species such as *Philodendron selluum* store fats which are "burnt" to create heat, so that the flowers heat up. Philodendrons may register 46°C (115°F) when the air is 4°C (39°F), and crocuses heat up to 15°C (27°F) above the ambient air temperature. The warmth generated is probably used to attract flies and heat-seeking insects to the pollen. Some plants (skunk cabbage, *Symplocarpus foetidus*), however, may use their heat to melt a hole in the spring snow, and so protect the blooms from cold [at 20–25°C (36–45°F) extra heat] as well as to provide a cosy incubator for the rest of the plant's growth" (*New Scientist*, 9 May '85) and to scatter odorous scents that attract pollinating flies. More amazingly, the shape of the first leaf of this species creates a vortex (from wind) that is contained within the hot leaf and carries pollen down to the unpollinated lower flowers, thus achieving fertilisation, in cold winds, without the presence of insects!

As all these "heaters" may have unpleasant smells, we should use them with caution. Understorey clumps of such species may assist frost-tender, fly-pollinated, or heat-starved plants, just as tall interplant systems may assist general heat requirements for some ground crops.

RADIATION AND GERMINATION OF SEED

The effect of soil temperatures alone on germination of a wide range of vegetable seeds can be profound. Between 0°–38°C (32°–100°F) the time to germinate (in days) can be reduced to one-tenth or one-fourth of that in cold soils by increasing soil temperatures. At the extremes of this temperature range, however, we find many plants have limiting factors which result in no germination. While almost all vegetable seed will germinate in soils at 15–20°C (59–68°F), such oddities as celery refuse to germinate *above* 24°C (74°F), and many cucurbits, beans, and subtropicals do not germinate *below* 10°C (50°F). Thus, we are really talking about waiting until 10°C is reached, or warming up the soil in greenhouses or with clear or black plastic mulch in the field before planting. Sometimes just the exposure of bare earth to the sun helps. A simple thermometer inserted 2.5 cm (1 inch) in the soil suffices to measure the soil temperature, or a special soil thermometer can be purchased. For specific crops, we can consult such tabulations as are found in Maynard and Lorenz (*Knotts Handbook for Vegetable Growers*, 1980, Wiley, N.Y.)

A second effect on germination is light itself, e.g. carrots need a definite quantity of light, and are usually surface-planted to effect this. We can surface-scatter such seeds, or first *soak* them overnight and then subject them to a day under a low-wattage light bulb or in the open before planting and covering them lightly (they react to this light *only if wetted first*). Larger seeds usually accept burial and germination in the dark, while some weed seed and desert seed will germinate deep-buried. For a few weed species such as wild tobacco, a mere flash of light (as when we turn over a clod of soil) suffices to start germination.

Next we come to *cold*, and we speak of the STRATIFICATION or VERNALISATION of seeds. Cold-area seed, and specifically tree and berry seeds from boreal or cold areas, should spend the period from autumn to spring in a refrigerator when taken to warmer climates. Apple seeds stored in sand or chestnuts in peat sprout in this way, and can be potted out as they shoot. This in fact reproduces the exposure to cold [at about 0°–5°C (32°–40°F)] that they normally experience at the litter level in cold forests or marshes. Wild rice and other "soft" aquatic seeds are stored in open ponds, or under water in an ordinary refrigerator.

Stratification can often be accomplished by keeping such seeds in sand or peat (or water for aquatics) in cold shaded valleys, or under open cool trellis in warm climates. They can be checked on late in winter and spring for signs of germination. The opposite of this is heat treatment, such as we can give to many tree legume seeds, by heating in an oven at 95°C (200°F) for a 10–20 minute period, or by pouring very hot (near-boiling) water over them, or by burning them in a light straw fire.

Many older gardeners will also feed seeds to themselves (in sandwiches), or their animals (chicken or cattle), collect the manure, make a slurry of it, and sow such seeds as tomatoes, berries, and tree legumes. The voyage through the digestive system is a compounded process of acid/alkali, hot/cold, mechanical cracking in teeth or in bird crops, and packaging in manure to which a lot of seeds are adapted.

FLOWERING

Day length (in fact, night length, but we will take the day side) varies over latitudes, and flowering plants are adapted to bloom and set seed in response to specific day lengths and the change of seasons. While many plants are DAY NEUTRAL and will flower if other factors are satisfactory, some will not flower at all in shorter or longer day–lengths than those to which they are adapted. This can be put to use, as when we transfer a tropical (short–day) corn to a temperate (long–day) hot–summer climate, and get a good green–leaf crop as fodder, or take tobacco from temperate to cool areas and get leaf rather than seed production. The same goes for some decorative foliage plants. But this effect is in fact the reason for choosing varieties from local growers, or selecting for flowering in new introductions so that a local seed source is available for all those crops we want in seed.

In New Guinea highlands (short days), cabbages from long–day climates may never flower, and some *Brassicas* reach 1–3 m in height, the leaves being plucked off at regular intervals for vegetable fodder, and the plant cut down only when too tall to reach!

Latitudes have specific day lengths as follows:

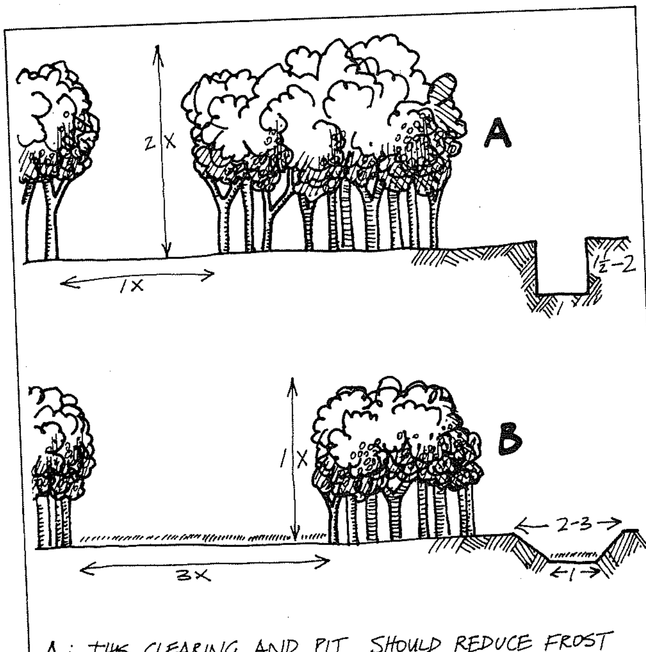


FIGURE 5.13
CLEARINGS IN TREES FOR FROST PROTECTION. (or pits in soils)
Frost loss is less in small steep–walled clearings that are about half the width of tree height.

- LOW LATITUDES (0–30°): Usually tropical climates, with colder mountain climates; equal or near equal days and nights.
- MID LATITUDES (30–50°): Cool to temperate climates with boreal mountain regions; long summer days and short winter days.
- HIGH LATITUDES (>50°): Very long summer days, and probably good radiation from diffuse light all the growing season. No plants grow in winter.

FROST

Frost is caused by radiation loss (rapid cooling) of the earth on clear nights, in still air. To reduce frost on any site (or in a small pit), it is necessary to have a *steep–sided* clearing or pit so that radiation is restricted to a small area of the sky. In such clearings, we have two effects: radiant heat from the vertical edges *plus* the obscuring of the horizon (hence less radiant heat loss at night). The proportion of heat loss on a cold night is proportional to the area of the night sky that is visible to the object losing heat. For example, a mouse in a cardboard tube in the ground loses very little heat, but a mouse on a mound on a flat sight is exposed to the whole sky and loses a great deal of heat.

The second factor is that the pit or clearing should be *small*; large clearings will create or contain *more* frost. The rule is to make the clearing (or pit) about one–half as wide as high, and to keep the sides trimmed to vertical. In forests, such clearings should not exceed 30m across (**Figure 5.13**).

It is necessary, therefore, to try to build up a complete crown cover to prevent frost on a site, and this is best done in stages. For example, we could plant the whole area to frost–tolerant legume like silver wattle (*Acacia dealbata*), then plant semi–hardy fruits in the shelter of these, eventually cutting back the *Acacia* as the frost–sensitive, protected trees gain height. It is obviously necessary to assist this process by supplying water to the selected trees, and this may also help ameliorate the frost effect on nights of high risk.

The effect of trees on soil moisture and frost may be profound at edges and in small clearings, as the tree crowns obviously create their own water distribution on the ground. Crown drip can direct in excess of 100% of rain to a "gutter" on the ground, and for some tree species with down–sweeping limbs and leaves, this is a profound effect. At the rain–shadow edges of forests, dry areas are to be expected. What makes this effect more pronounced is that the "wet" edges are more often than not also away from the sun (most rain comes from the polar side of sites). **Figure 5.14**.

The sunny edges of the forests help protect seedlings from frost, and these and small clearings are used to rear small trees, or to plant them out in frosty areas.

Some implications for designers are as follows:

- IN COMMUNITY AND PLANT HEALTH: Areas of severe direct or diffuse radiation, and especially where the atmosphere is thin (on mountains), where albedo is high (in snow, granite, or white sand areas, or over hayfields in summer) can produce severe radiation burns, skin cancers (very common in Australia), and temporary or longterm blindness.

Plants, too, must be screened against sunburn by partial shade and by white paint on their stems in conditions of severe radiation (especially young plants). Older plants may suffer bark damage, but will survive.

• FOR AUTOMATIC TRANSFER thermosiphon effects are best achieved by:

- placing heat sources below storage and use points;
- inducing cross–ventilation by building **solar chimneys** to draw in cool air;
- actively fanning heated air to underfloor gravel storages where solar attics or trapped ceiling heat is the heat source; and
- eliminating heat–induced condensation through the use of heat exchangers.

• IN HEAT STOVES: Massive earth, brick, stone, or concrete heat storage masses must be insulated to retain heat that is otherwise lost by *conduction* to the ground, or by radiation to the exterior of houses. Conduction is prevented by solid foam or air–trap insulation (straw). Radiation loss is prevented by reflection from double–glazed windows, or reflective insulation hanging in air spaces.

Reflective insulation doesn't work if it is dusty, dirty, or pressed against a conducting surface, hence it is of most use as free–hanging sheets, or ceiling sheets looped loosely across rafters. It can be kept clean (and effective) only in such situations as solar attics. Plain white paint is an excellent reflector for everyday use on walls or in concentrators.

• PLANT CHOICE: All plants with high biomass (e.g. trees) store heat in their mass (which is mainly water). Thus, fairly small clearings may be frost–free in cold climates. Dark evergreen trees absorb (and radiate) heat effectively; white–barked, shiny, or light–coloured trees reflect heat in cool districts, on forest edges, and where light itself is a limiting factor.

• WATER AND STONE are good heat storages, having a high specific heat. Thus, bodies of water are good heat storages. Air has a low specific heat and is a very poor conductor of heat, hence a good insulator. Many insulation systems work simply by trapping air, or by being poor conductors (cork, sawdust, wood).

These short examples, and some of the tabulated material, give the essential features of radiation that are applicable to everyday design. A preliminary design choice is to choose house sites for the maximisation of solar radiation in subtropical to cool climates and to shelter from radiation where excessive heat is a problem. Excess heat in one area of a house can be used in arid and tropical areas to "fuel" a cross– ventilation system, also essential in the humid tropics for cool dry air intake to the home.

Designers should always be aware of opportunities to convert light to heat, to reflect more heat on to cool areas, to light dark areas by reflection or by skylight placement, and to store heat below insulated slab floors.

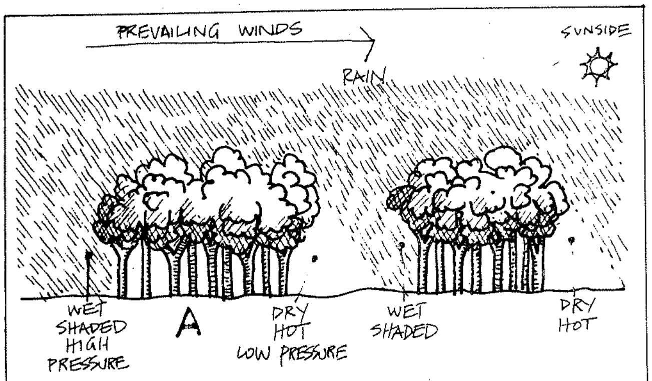


FIGURE 5.14
WET AND DRY SIDES OF A FOREST CLEARING.
Microhabitats develop due to combined sun and rain effects.

5.6 WIND

Both wind and water transport can influence (by impedence or reflection) the quantity of light and heat on any site. Particles or molecules carried in air have a profound effect on available light, and heat can easily be transported about our system by air and water, or by substances mixed in with them.

Of all of these elements, we have least control of wind in terms of storage or generation, but we can control its behaviour on site by excluding, reducing, or increasing its force, using windbreak and wind funnels to do so.

As a resident of a bare, cleared (once–forested) peninsula, when I speak of wind I know of what I write! The very table on which this book is penned rocks to gusts from the "roaring forties" and when the wind blows from the east, spicules of salt form on beards, clothes lines, and plants, burning off leaves and killing plant species; some hardy plants that withstand years of normal gales can die in salty summer winds.

When it comes to crop, winds of 8 km/h are harmless. Those of 24 km/h reduce crop production and cause weight loss in animals, and at about 32–40 km/h, sheer mechanical damage to plants exceeds all other effects; in fact, I have seen my zucchini uproot and bowl along like a tumbleweed. Trees are severely wind–pruned by a combination of mechanical damage and salt burn near coasts, and by the additional factor of sandblast in dunes (desert or coasts) and iceblast in cold climates. Wind transport of sands in deserts and incipient deserts buries fences, buildings, trees, and crops.

Although many sites are little affected by wind as a result of fortunate local conditions, or a general low level of wind effect in a region, very few coastal, island, sub–tropical or exposed hill sites can afford to ignore this factor.

There are broad categories of wind speed and effect, just as there are for rainfall and temperature. The Beaufort Scale is the normal way to report winds, and equivalents are given in **Table 5.5**.

More severe than mechanical damage are the minute sulphur and nitrogen particles carried by wind. In Colorado, Virginia, Utah, the Urals and in fact anywhere downwind of nuclear waste stores, tests, and accidents we can add plutonium and other radioactives to the wind factor. Dry sulphur, falling on leaf and soil, converts to acid in misty rains. On parts of the northeast coast of America and Canada, these rains can burn gardens and forests, or make holes in garments and tents in a few days. Near acid production factories, even paints and roofing are pitted and holed; this factor has become general in industrial areas and for many miles downwind.

Windbreaks may mean the difference between some crop and a good crop, but in severe wind areas, the difference is more absolute and may mean that susceptible plants will produce no crop at all. Thus, a list of wind–tolerant (frontline– trees) is a critical list for food production and animal husbandry.

DIRECTIONS AND SEASONS

Winds are fairly predictable and often bi–modal in their directions and effects in local areas. For the landscape designer, **wind–flagging** or older trees and wind-pruning tell the story; the site itself has summed total wind effects over time.

From Latitudes 0° to 35° north and south in oceanic areas, winds will be bi–modal and seasonal, southeast or northwest in the southern hemisphere, southwest or northeast in the northern hemisphere. Locally, the directions will be modified by landscape, but the phenomena of windward and leeward coasts are almost universal. From Latitude 35° to the limits of occupied coasts, westerlies will prevail in winter, easterlies more sporadically as highs or lows pass over the site and remain stationary to the east or west. Cold winds will

BEAUFORT NO.	KNOTS	km/h	MPH	DESCRIPTION
1	1	1	0.5	Calm
2	1 - 3	1 - 5	1 - 3	Light airs
3	4 - 6	6 - 11	4 - 7	Light breeze
4	7 - 10	12 - 19	8 - 12	Gentle breeze
5	11 - 16	20 - 28	13 - 17	Moderate breeze
6	17 - 21	29 - 38	18 - 24	Fresh breeze
7	22 - 27	39 - 49	25 - 31	Stormy breeze
8	28 - 33	50 - 61	32 - 38	Near gale
9	34 - 40	62 - 74	39 - 46	Gale
10	41 - 47	75 - 88	47 - 55	Strong gale
11	48 - 55	89 - 102	56 - 64	Storm
12	56 - 63	103 - 117	65 - 73	Violent storm
13	64 +	118 +	74 +	Hurricane

BEAUFORT NO.	EFFECTS	
0 - 2	Slight, no damage to crops or structures	
3 - 4	Damage to very susceptible species	Useful energy produced
5 - 6	Mechanical damage to crops, some damage to structures	Useful energy produced
7 - 12	Severe structural and crop damage. Damage to windmills.	

THE REDUCTION OF WIND VELOCITY IN FORESTS:

Penetration (m)	Remaining Velocity (%)
30	60 - 80
60	50
120	15
300 - 1,500	Neglible wind.

TABLE 5.5
THE BEAUFORT SCALE.

blow from continental interiors in winter, and warmer but still chilling winter winds blow in from the seas.

Islands and peninsulas from Latitudes 0° to 28° eperience two main wind modes, those of the winter winds or trade winds (southeast in the southern hemisphere, northeast in the northern hemisphere) and those of the monsoon. In effect, we look for two seasons of winds and two short periods of relative calms or shifting wind systems in these latitudes. These are the main winds of tropical oceanic islands.

In summer, the cross–equatorial monsoon winds deflect to blow from the northwest in the southern hemisphere, and as southwest monsoons in the northern hemisphere. Southeast Asia and the Pacific or Indian ocean islands are most predictably affected by these bi–modal systems. Although many sites are also affected by only two main strong wind directions, these are rarely as strictly seasonal in effect as they are closer to the equator.

WIND LOADS

On warm sea coasts, where onshore winds not only carry salt but also evaporate moisture, salt deposits on vegetation are the limiting factor on species selection, and only selected hardy species with fibrous or waxy surfaces can escape death or deformation by salt burn.

As well as inorganic materials, wind may transport organisms ranging from almost impalpable spores of fungi and ferns to very weighty insects such as plague locusts which are swept aloft by heated air columns, and carried as frozen or chilled swarms to down–draught areas. Here, they thaw out and commence feeding, or perish in oceans far from land. Mosquitoes, fruit flies, wasps, and spiders deliberately spin aerial floatlines and also migrate over mountain and oceanic barriers on windstreams. Flocks of migrating birds also take advantage of windstreams as they circle the globe.

Flow of air (wind) over leaf surfaces promotes rapid transpiration, as does high light intensity (Daubenmire, 1974). When we have both effects together, shrubs and trees may lose too much water, and trees guard against this combined factor by presenting whitish undersides of leaves to the light as the wind blows, thus carrying on a dynamic balance between the light and wind factors. Vines and trees may alter leaf angles to reflect light, trap air, or to reduce the area of leaf exposed to light or wind. Thus, both pigmentation and leaf movement are used to balance the effects of variable incoming energy, and leaf pores close down to prevent moisture loss.

WIND HARMONICS

In a radio programme on sailing (Australian Broadcasting Corporation, 19 Dec '84), Frank Bethwaite, a New Zealand–born Australian boat designer, pilot, and sailor outlined some of the characteristics of ground winds. Such winds do not blow steadily, but vary as gusts and calms in a predictable and locality–specific way; that is, the common winds of any one site have regular pulses.

He states that such regular variations are easily timed; a 49–60 minute frequency of gusting is typical of mid–latitudes, with gusts 40% stronger than lulls. In lulls, the wind *direction* also changes, as light crosswinds at about 15° to the main wind direction.

The variation in wind speed and direction is systematic and regular, and both frequencies, durations, and amplitudes can be obtained by combinations of stopwatches, anemometers, and wind vanes (or all of these recorded on automatic equipment).

Such "waves" of wind are made visible in grass-lands, or on the surface of waters viewed from a cliff. They are also, at times, reflected in clouds as "rank and file" systems. The lulls show as spaces between cloud ranks, and in these spaces, light clouds of different alignment represent the change of direction typical of lulls.

The gusts are ponderous, representing vortices; the lulls are of light crosswinds. Some periods are short (Bahrain, 5.25 minutes; Sydney, 6–12 minutes; Toronto, 10 minutes). Wave "fronts" on grasslands may come at every 14 seconds, with gusts at longer intervals. Sea waves themselves have a characteristic periodicity and speed, usually about 5–12 per minute, the period lengthening in storms.

In the westerly wind belts, we can distinguish between the PREVALENT WINDS of from 8–24 km/h, which blow for five out of seven windy days, and the ENERGY WINDS of from 16–40 km/h which blow on the other two days. The energy winds come from between 15°–20° off the direction of the prevalent winds (Michael Hackleman, *Wind and Windspinenrs*, Peace Press, California, 1974).

WINDBREAKS

It is the chill factor—the removal of heat from surfaces, and evaporation of fluids—that creates cool to cold climates in the tropics at lower altitudes than adiabatic or altitude factors would indicate. This chill factor retards plant growth, and lowers the efficiency of solar devices and insulation. In cyclonic or hurricane areas, catastrophic winds may become the over–riding design modification, around which all other factors must be arrayed.

We are not much concerned with sheltered and low wind–energy sites, except to choose them for our dwellings in exposed landscapes, but close attention must be paid to shelter strategies in exposed sites.

On sites with predictable wind patterns, revealed either by trees, derived from local knowledge, or indicated by wind records over time, we can plan directional, patterned windbreak of earthbank and trees. On sites where severe winds and sandblast may come from any direction (as in some deserts), the strategy is to impose a close rectangular or network pattern on windbreak.

However the windbreaks are arranged, buildings, gardens, and animal shelters can be arranged to face the sun and benefit from solar impact.

Essentials of a Windbreak

The essentials of windbreak are fairly well known and local lists of species for windbreak are often available from forestry and agricultural advisors or departments. Essentials are:

- Good species selection to be used as pioneers (easily grown);
- Initial protection of planting from mechanical or wind damage (bagging, fencing);
- Periodic or trickle irrigation to reduce desiccation;
- Anchoring by stones or mulch; and
- Species with 40–50% penetrability in the front line or as dominants.

Many fire–resistant plants are also wind resistant, and in addition to these, some drought–resistant but fire–prone species (pines) will withstand wind. What they have in common are ways of resisting desiccation and sandblast. Such plants have, as common features:

- Fibrous stems (palms).
- Fleshy leaves (aloes, agaves, *Euphorbias*).
- Hard, needle–like leaves or stems (pines, tamarisks, *Casuarinas*, some *Acacias*).
- "Furry" or hairy (tomentose) leaf covers, or waxy leaves (*Coprosma*, eucalypts, some pines, some *Acacias*).

Initial protection can come from:

- Individual open–ended plastic bags around stakes (a common and effective establishment method).
- Earth mounds, or side–cast earth banks of greater length than the tree line.
- Brush fences, even wire–mesh fences, or staked fences with 40% wind penetrability.
- Tussock or tough unmown grass to windward (leave if already present).

All of these can be used in combination in very hostile areas. It is usual for the windward rows of trees to be heavily wind–flagged, and for taller species to be placed in their lee. On coasts and in deserts, it is not until after the fourth or even fifth tree row evolves that wind–prone fruit or nut–bearing trees will yield, so windbreak is the *first* priority for gardens in these situations.

Substantial trellis is a more immediate alternative, but care should be taken to make this sinuous (if of brick or mud brick) or zig–zagged (if of timber), as it has to withstand persistent and severe forces until shelter grows on either side of it. Earth mounds can be better streamlined, being less sensitive to windthrow. The hollow from which the earth is taken to make the mound can be made to hold water or to give protection to young plants.

Tyre walls are sometimes feasible, and create great warmth inside the tyres, but are scarcely aesthetic unless very regularly arranged and planted. They have the advantage of being cheap, and can be removed once effective. Mesh fences, if stoutly built with a heavy top rail, can be the basis for fedges (fence–hedges) of thick–leaved vines, which on coasts may completely mound them over with tough semi–succulents such as *Rhagodia*, *Tetragonia*, *Carpobrotus*, or *Mesembryanthemum*. Rock walls and tyres may be similarly mounded with scramblers or cacti, some of which provide bee forage

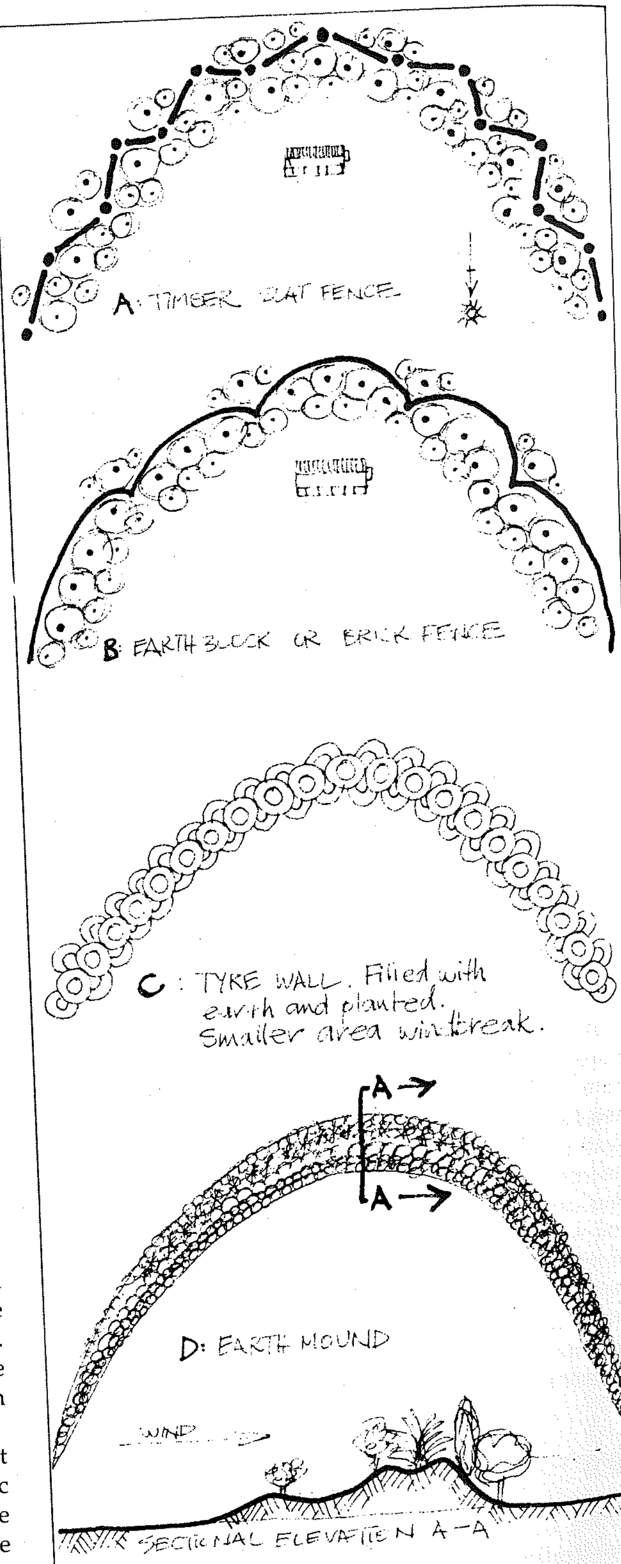


FIGURE 5.15
METHODS OF ESTABLISHING WINDBREAKS.
A variety of stable windbreaks using different materials.

and berries or edible fruits.

It is rare for tree canopies on dry saltwind coasts to gain more than 46 cm height in 1 m width (18 inches in 3 feet), so considerable width must be given to pioneer windbreaks in these situations, unless those hardy pioneers such as the Norfolk Island pines can be nursed to grow to windward. However, as this slow climb to height commences from *ground level*, a fence, building, earth bank, or barrier gives it a great start for far less spread (**Figure 5.15.D**).

Even a 46-62 cm (18-24 inch) high "fence" or mound earth will grow a sweet potato, strawberry, or cabbage in the lee, while hard–pruned canopies need not be barren, as many dwarf fruit, vine, and flower crops will grow below these if mulch and water are provided. In windbreak forests near coasts, small openings of 6–9 m (20–30 feet) provide garden shelter and admit light.

There is, in fact, a special charm about those 3–3.5 m (10–12 feet) high dense coastal shrubberies in which nestle small shacks, through which wander sandy paths, and in which people create small patches of scattered garden using wastewater and mulch. Once shaped, fruit trees in this situation seldom need pruning, and at times one wonders if the wind is not an advantage in that it forces compact and careful work, punishes carelessness, and promotes wastewater use.

Across the whole of the flattish peninsula of Kalaupapa on Moloka'i, the Hawaiians had built tiny stone fences of 25–50 cm (10–20 inches) high and only 4.5–5 m (15–18 feet) apart, behind which they grew a basic sweet–potato crop, and in which grew tough fern for mulch. All are now abandoned, but on the seaward coast, wild date somehow struggles to 4.5 m (15 feet) or so in the teeth of the tradewinds, and would have made a grand windbreak had the Hawaiians retained their land against tourism and graziers. Just to windward, the strong winds bring so much salt spray ashore that it crystalizes out in pinkish ponds, mixed inexorably with the red of the volcanic earth on which it forms. Even today, it is gathered as "Hawaiian salt", and is further mixed with the roasted kukui nut and chilies for a delicious raw–fish condiment.

Some Benefits of Shelterbelt

1. *Shelterbelt effects on house design.* For glazed areas and hot water (flat plate) collectors, wind chill factors remove 60% of heat alone. Shelterbelt (including thick vine trellis) around a house can effect a 20–30% saving in heating fuels in moderate to severe winters. Thus, in cold areas earthbanks plus shelterbelt, and a sun–facing aspect, is a critical design strategy. In deserts, where advected (wind–carried) heat is the most severe effect on human comfort, shelterbelt trees serve to reduce ground temperatures up to 15°C.

2. *Effects of exposure on livestock.* Blizzards will kill livestock and newborn lambs, and even hardy and adapted animals can lose 30% of their bodyweight in 3 days of blizzard. As well as shelterbelts in fields, we need to be very careful to design fences so that they do not form downwind or downslope traps, as herds escaping blizzards will pile up against them and smother in fenced corners. All moorland and high plateau fences should allow easy downwind escape to woodlots, sheltered valleys, or lower elevations.

In less severe conditions, sheep weight in unsheltered fields in New Zealand is 15% less than that of sheltered areas. Australia attributes 20% of all lamb losses to wind chill factors, and issues regular wind chill warnings at shearing time to prevent adult sheep loss.

Cattle fed winter rations on exposed sites will eat 16% less of this food, so that winter hay and concentrates need to be fed out in shelter for animals to obtain full benefit. Both heat and cold have similar effects on weight gain, and shelterbelt is one of the most effective ways of increasing livestock production, and conserving rations. Thus, in designing for livestock, fences, shelter, access to shelter, and feeding and watering points all need sensible placement, so that animals are not exposed to extreme temperatures. In the tropics and subtropics, a ridge planting of pines or *Casuarinas* with a wind gap left below the crowns affords both shade and an induced breeze that discourages flies and mosquitoes. Such ridges are also rich mulch sources for lower slopes.

3. *Civil construction.* Snowdrift across highways is more effectively and permanently blocked by hedgerow of hardy *Caragana* and *Eleagnus*, which are estimated to be 50% cheaper than stout fences, and of course outlast them. Juniper in high country actually grows better in areas of snow drift (below the sharp ridges where snow forms cornices), and swales at such places enable more snow melt, therefore more available root moisture for trees in spring and summer.

Wind shear on exposed highways or at caravan parks can cause casualties and property damage, so that we need to design windfast median strips and highway shelterbelt in areas of known hazard, but especially on mountain passes and near exposed coasts subject to gales.

4. *Shelter in and around croplands and orchards.* For croplands, a matrix of shelterbelt species 10–16 m in height and 33–66 m apart (*Casuarina*, poplar, Matsudana willow, trimmed eucalypt) affords wind protection for such crops as kiwifruit and avocado, and give the greatest increases in yield while reducing wind damage to fruit and leaf. For instance, citrus culled as damaged is 50% of the crop in unsheltered areas, versus 18.5% in shelterbelt systems, cotton yields are 17.4% higher within five times the height of the shelterbelt, and fall off to a 7.9% advantage at ten times the height of the belt.

Effects of shelterbelt are compound, and include more meltwater from snow, much greater fruit or seed set in bee–pollinated crop, the preservation of good shape in the trees, hence less pruning. Species selection of shelterbelt trees is essential, and a set of factors can be the criteria that assists the farm enterprise sheltered. These include:

- Nitrogen fixation or good mulch potential from leaves and trimmings;

- Hosting of predatory insects or birds that control crop pests;
- Least moisture competition with crop (although roots from the shelterbelt can be ripped or trenched at the edge of crops);
- Excellent forage yields or concentrated foods for livestock; and
- Natural barriers to livestock (thorny plants, or woven hedge).

Shelterbelt is planted as a succession from a tall grass to a taller legume to a long–term, tall, windfast hedge of e.g. *Casuarina*, poplar, willow, eucalypt, oak, chestnut. All this complex can be set out at once, and managed as it evolves to maturity. Quickset (by cuttings) hedges of poplar and *Erythrina* are popular because of their fast windbreak effect, but species must be chosen to suit a particular climate.

Where space is ample and winds strong, the profile of a windbreak can be carefully streamlined, and up to six rows of tree and tall grass lines established, giving a mixed yield of forage, timber, fuel, mulch, honey, and shelter. In more constricted areas, a matrix of single–tree lines is usual, and effective if close–spaced. However, there is no such thing as a standard shape or windbreak, and very different configurations are needed for different sites, functions, and as accessory species to the enterprise sheltered, the wind strength, and the wind load (salt, sand, dust).

5. *Effects of windbreak on soil moisture.* Windbreak is very effective in snowy areas, increasing soil moisture 4% to four times the height of the break, and that to 1.2 m depth in soils. Obviously, the benefits to trees in cold deserts are as a reserve of soil moisture that is rare in cold dry climates. The same effect occurs locally in the lee of tussock grasses, and can be used to establish a tree.

In foggy climates or facing sea coasts, we must add the effect of sea air condensation, which can be from 80–300% of rainfall as leaf drip. In hot deserts and hot winds, the advected hot winds are the major factor in soil moisture loss. Such effects are produced over large treeless areas of dry grain crop as well as in deserts.

The effects on grain crop of windburn and seed shattering in hot winds is insignificant for up to 18 times the height of the windbreak.

6. *Less soil loss due to windstorms.* Very serious soil losses of up to 100 T/ha/day in duststorm episodes (usually followed by torrential rain) are prevented by windbreak and soil pitting with tussock grasses. Approximately 50–70% of dusts settle out of the air 100 m into tree clumps, so that treelines are the essential accompaniment to any pastoral or crop system in arid areas.

On coasts, removal of mangroves and coastal dune vegetation results in a sudden acceleration of wind erosion on beaches and coastal soils, and following deforestation, up to 30% more silt per annum flows into and reduces the useful life of water storages.

7. *Windbreak and hedgerow as accessory to crop and livestock.* Quite apart from the above effects, windbreak species can be chosen to provide excellent crop mulch (*Prosopis, Acacia, Erythrina, Melia, Canna*) and fodders (all the foregoing species plus *Leucaena*, Fig, *Pennisetum*), and also to fix or recycle nitrogen and phosphatic fertilisers, or to mine trace elements (*Casuarina, Banksia, Eucalyptus camaldulensis*).

Dry or cold–deciduous species and monsoon deciduous trees give a natural leaf fall in crop, automatically adding growth elements to the crop. In every crop and orchard it is advisable to interplant leguminous trees for mulch, soil building, and in–crop windbreak or frost cover. Trees like avocado and crops like papaya can be grown on sub–tropical frosty sites providing there is a high canopy of hardy palms or light–crowned legumes (e.g. Butia palm, *Jacaranda, Tipuana tipu*). Such sites do not frost, as there is no bare–ground radiation at night, and advected frost is impeded.

Finally, forage and firewood from windbreak provides excess fuels to cook crop products, which is an important factor in the third world. In summary, well–chosen and designed windbreak can occupy up to 30% of the total area of any site without reducing crop yields, and if windbreak species are chosen that aid the crop itself, there will be an increase in total yield, soil quality, and moisture available.

<u>Hedgerows and Shelterbelts</u>

Shelterbelt species must be carefully selected to give multiple uses, to either ASSIST the crop yield, or ADD TO the end use yield (e.g. forage trees in pasture). This ensures the area occupied by shelterbelts adds to the

PERMEABILITY	WINDSPEED REDUCTION	DISTANCE OF EFFECT (H=Windbreak Height)
60%	20%	12 x H
50%	50%	27 x H
0%	100%	15 x H (with severe eddies)

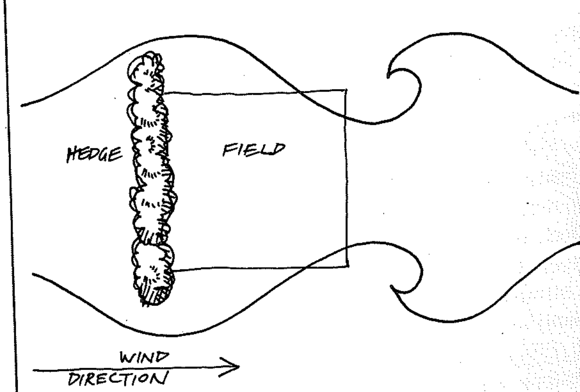


FIGURE 5.16
PERMEABILITY OF WINDBREAKS.
This figure shows how winds flow around a windbreaks which needs to be wider than the field for less permeable hedgerow.

total crop yields, rather than deducts from them. In general, we would gain in crop *or* pasture yield using nitrogen fixing and browse–edible shelterbelts species, and lose crop yield by using high water-demand, non-leguminous, and inedible shelterbelt species.

However, where we experience severe sea or desert winds, which greatly reduce all yields, we must select salt–resistant or sand–blast–resistant windbreak no matter what the intrinsic yields of the shelterbelt. It is rare for sea–front trees to bear effectively (e.g. the outer 4–5 rows of coconuts on exposed islands yield little crop), so that choice of frontline seacoast plants for seed or fruit yields is often irrelevant when considering species for multiple function.

For isolated trees, or trees whose canopy lifts above the general forest level, wind of even low speeds may increase the transpiration rate, sometimes doubling water use. The effect is greatest on water–loving plants, and much less on dry–adapted species which have impermeable leaf cuticle and good control of stomata, or a cover of spines and hairs.

Hot, dry winds, and winds laden with salt have the most damaging effect on plant yields (hence, animal yields), although at high wind speeds mechanical damage can occur, which prevents or reduces yields no matter what the humidity or salt content of the winds. Damaged crop plants such as corn or bananas suffer photosynethic inefficiency ranging from 20–85% when the leaf laminae are torn or frayed, or the midribs are broken (Chang, 1968).

Plants show different resistances to wind damage:

- *Wind tolerant* (and wind–fast). These are the many short or creeping plants at the boundary layer of still air near the ground, or the front–line plants of sea coasts, e.g. *Cerastium, Araucaria heterophylla* Yields are little affected by strong winds.
- *Exposure tolerant*, e.g. barley, some *Brassicas*, *Casuarina* and *Coprosma repens*. Yields are reduced in strong winds, but dry matter yield is less affected than in wind–sensitive plants.
- *Wind sensitive*. These are the many important crops such as citrus, avocado, kiwifruit–vines, many deciduous fruits, corn, sugar cane, and bananas. Both plant height and yields rapidly decrease with increases in wind speed. For these species, very intensive shelterbelt systems are essential.

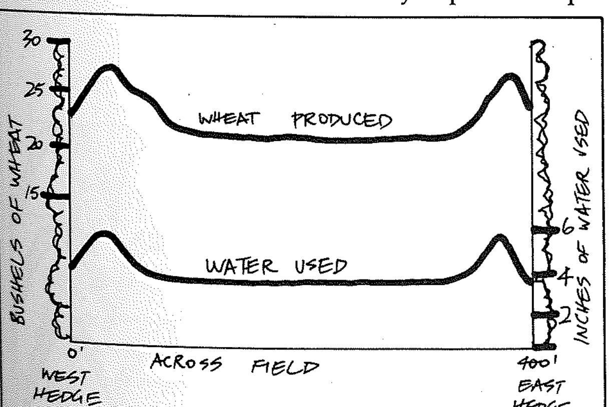


FIGURE 5.17
WATER USE AND WHEAT PRODUCED.
The efects of hedgerow increase yields on both sides but increase water use.

Problems arise when the plants used for shelterbelt (e.g. poplar) are themselves heavy water–use species with invasive roots. An annual root–cutting or rip–line may be necessary along such windbreaks to permit the crop sheltered to obtain sufficient water, but it is best to choose more suitable species in the first place.

Windbreak Height and Density

The height and density, or penetrability, of windbreak trees are the critical shelter–effect factors. Some configurations of windbelt may causes frost–pockets to develop in the still air of sheltered hollows. PERMEABILITY is an important factor if we want to reduce frost risk or to extend the windbreak effect (**Figure 5.16**).

Briefly, we need windbreaks spread at *no more than* 20 times the hedgerow height in any severe wind. In the establishment of wind–sensitive tree crop we may actually need continuous (interplant) windbreak. The length of windbreak needs to be greater than the length of the field protected, as wind funnels around the end of windbreaks in a regular flow pattern.

Windbreak Configurations

In general, species chosen for windbreak should permit 40–70% of the wind through, which prevents the formation of a turbulent wind overturn on the leeward side. Windbreak height is ideally one–fifth of the space between windbreaks, but is still effective for low crop at one–thirtieth of the interspace.

Sensible configurations are shown in **Figure 5.18**. Note that some wind shelter systems are placed throughout or within the crop or fruit area.

A. *Dense windbreak* with bare stem area below. Effects: good summer cool shade for livestock; poor to useless winter shelter. Clumps of such trees on knolls allow animals to escape heat, and flies and mosquitoes are much reduced.
Sample species: *Cupressus, Pinus, Casuarina.*

B. *Alternate* (zig–zag) planting of very permeable trees. Effects: good "front–line" seafront systems to reduce salt burn and provide shelter for more dense trees on islands and coasts. Species: *Araucaria, Pinus, Casuarina.*

C. *Compound windbreak* of high density. Effects: The best protection for eroding beaches, lifting the wind smoothly over the beach berm and trapping sand. Also effective in dust–storm areas as a dust trap. Species: Ground: *Convulvulus, Phyla (Lippia), Mesembryanthemum.* Low shrubs: *Echium fastuosum*, wormwood. Shrubs: *Coprosma repens.* Trees: *Lycium, Cedrus, Cupressus*, some plants.

D. *Permeable* low hedgerow of *Acacia* or legumes. Effects: Good effects on grass and crop growth, allows air movement to reduce frosts. Species: *Acacia, Leucaena, Prosopis, Albizia, Glyricidia,* tagasaste and like tree legumes.

E. *"Incrop "windbreak*

1: Savannah–style configuration of open–spaced light–crowned trees in crop or pasture. Effects: Excellent forage situation in arid areas, especially if trees provide fodder crop; pasture protected from drying winds. Species: Several fodder palms, *Inga, Acacia,* tagasaste, baobab, *Prosopis.*

2: Complete or almost–complete crown cover *in* tree crop. Effects: Excellent frost–free sub–tropic and tropic lowland configuration where fruit trees (F) are interplanted with leguminous trees (L) as shelter and mulch, with *Casuarinas* (C) as borders. Suited to humid climates, or irrigated areas. Species: Fruits (F) from palms, avocado, *Inga,* banana, citrus. Legumes (L) of tagasaste, *Acacia, Albizia, Inga, Glyricidia, Leucaena.* Borders (B) of *Casuarina,* low palms (*Phoenix canariensis*), *Leucaena, Prosopis,* and other wind–fast trees and tall shrubs.

The partial list of windbreak configurations given above covers only some cases, and in every case a designer must select species, study suitable total conformation, and allow for evolution or succession. As with all permaculture designs, general known principles are followed but every actual site will modify the design, as will the purposes for which shelter is intended.

Windbreak is essential for many crop yields, particularly in orchards. As discussed, wind causes mechanical damage, salt–burn, and may transfer (advect) heat and cold into the crop. Unless conditions are very severe, single–line windbreak spaced at 15 times height may have a satisfactory effect on ground conditions, and this is recommended for crops and grasslands. However, severe montane and coastal winds need more careful design, and a complex windbreak of frontline species able to buffer the first onslaught of damaging winds is needed (**Figure 5.19**).

For both tree crops and orchards, we have a very different potential strategy in that the windbreak may be composed of trees compatible with the protected forest or orchard system we wish to shelter, and can then be integral with the crop (**Figure 5.18 E1** and **E2**). Great success with such strategies has been demonstrated both for wind and frost moderation in susceptible crop such as citrus, avocado and macadamia nuts or chestnuts, using a protective interplant of hardy *Acacia, Casuarina, Glyricidia,* tagasaste, or *Prosopis* spaced *within* the crop. As all of the windbreak species mentioned fix nitrogen or phosphates, provide firewood, radiate heat, and shelter crop, it is sensible and beneficial to fully interplant any susceptible tree crops behind barriers of front–line windbreak. Windbreak in this instance is integral with the crop (as it is in natural forests).

The importance of windbreak extends to SOIL CONSERVATION. In dry light soils, windbreaks can reduce dust and blown sand to 1/1000th of unsheltered situations (Chang, 1968) within 10 times the height of windbreak. Thus, in crops in arid or windy areas, it is necessary to plant windbreaks closer together for the sake of soil conservation. The loss of soil at 20 times windbreak height is 18% of open situations, which is still too much when we can lose 8–40 t/ha in windstorms!

Similarly, WATER EVAPORATION can be halved in strong winds (32 km/h or more) for distances up to 10 times height. Over 24 km/h, 30% gain in soil water conservation is achieved. Only in still–air conditions is evaporation loss about the same for sheltered and open field conditions.

SNOW MOISTURE is increased by a windbreak of type A or B (**Figure 5.18**) when the snow is trapped on fields. The snow depth in winter bears a close correlation to dry matter yields in spring and summer,

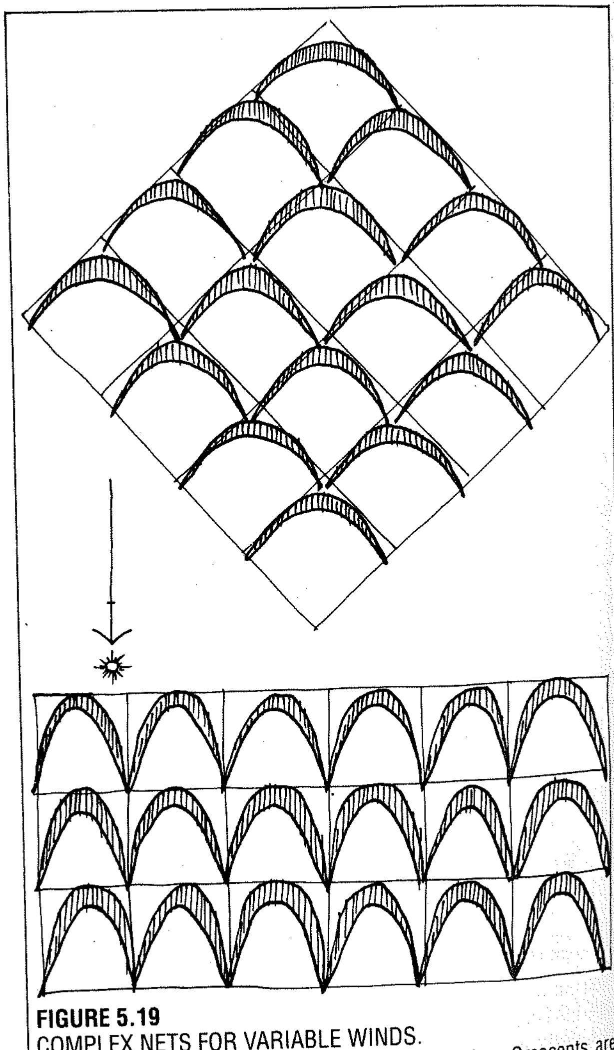


FIGURE 5.19
COMPLEX NETS FOR VARIABLE WINDS.
Two examples are given to suit straight–line fencing. Crescents are bowed towards the most damaging winds.

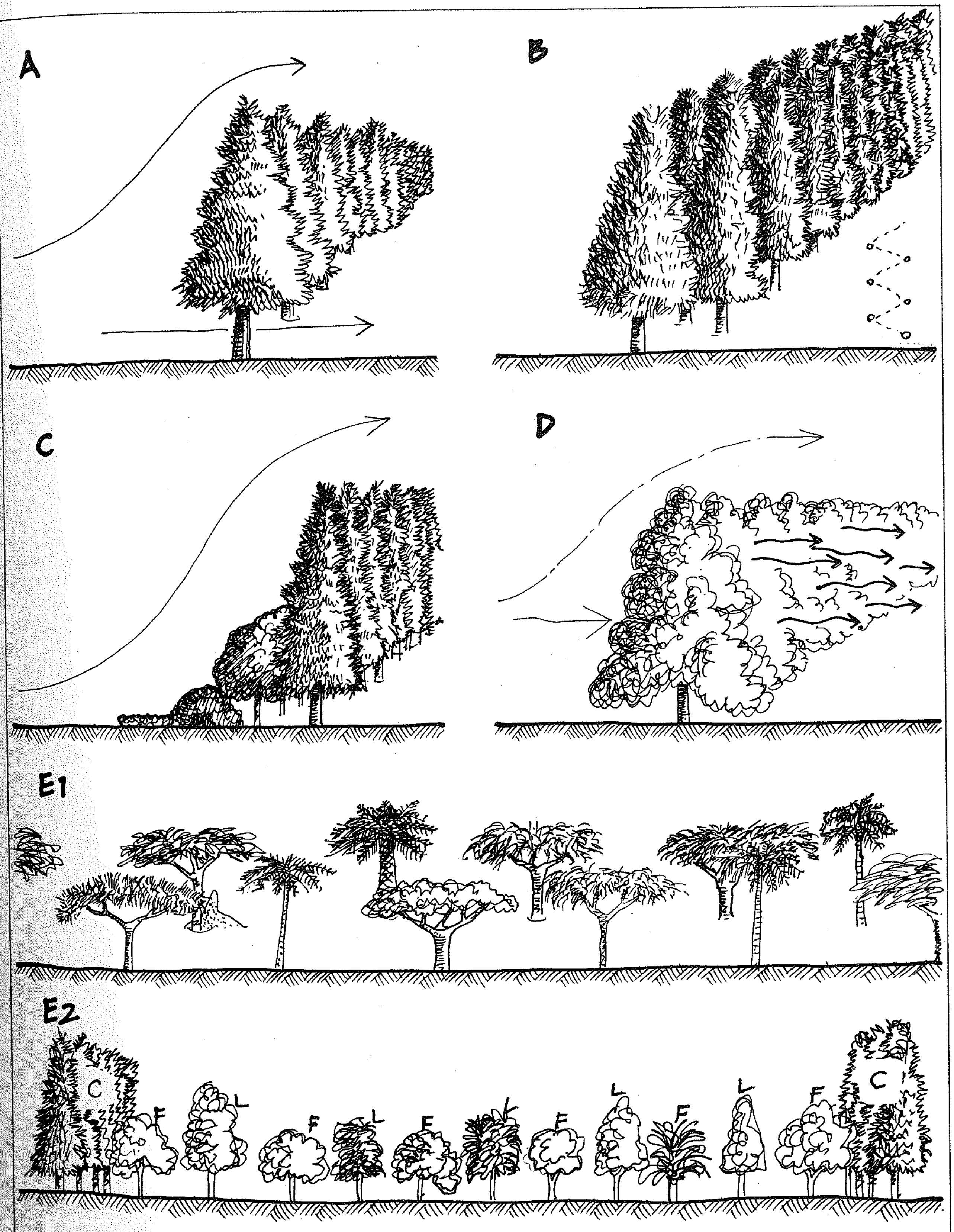


FIGURE 5.18
WINDBREAK CONFIGURATIONS.
There is no "best" windbreak; every crop, site, or condition needs specific analysis. Here, A suits ridges , B tall vine crop, C coasts, D fields, E1desert crops, E2 mesothermal orchards.

so that crop yields are highest downwind from windbreak areas. Wherever snow blows across the landscape, windbreaks of savannah configurations create spring soil moisture traps. It is also possible to do this by using open swales in snow–drift areas. Windbreaks in exposed snowfield areas can be better established in the lee of earth bunds or in natural cornice just polewards of ridges.

CROP YIELDS vary in increase from the 100% increase in such crops as avocado to 45% in corn, 60–70% in alfalfa, 30% in wheat, and lesser gains (7–18%) for low crops such as lettuce. All these increases follow windbreak establishment on exposed sites. Effects are of course less in naturally sheltered situations or areas of normally low wind speed. However, almost all normal garden vegetables (cucurbit, tomato, potato) benefit greatly from wind shelter. For this reason, a ground pattern similar to that in **Figure 5.20** is recommended for such crops and wind–affected pastures.

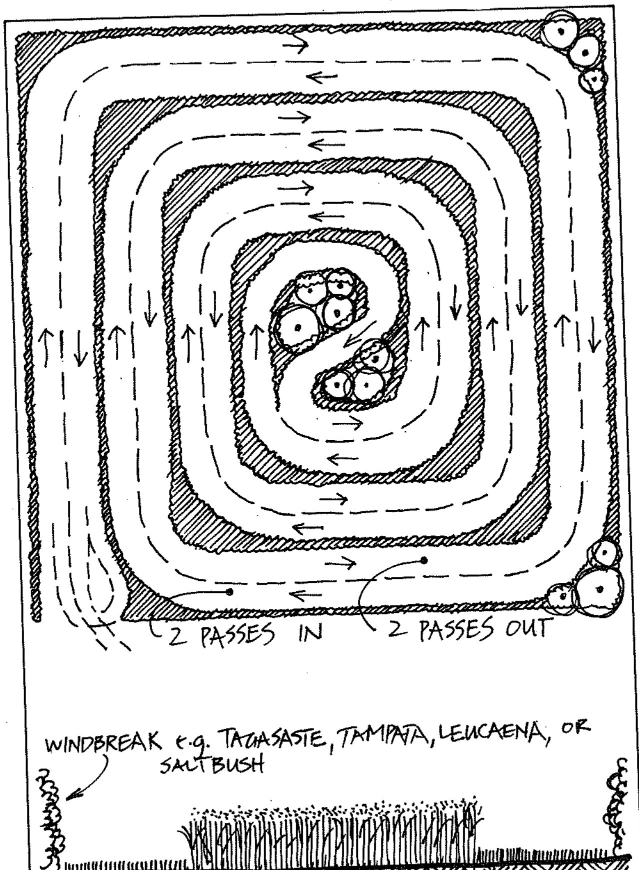


FIGURE 5.20
LOW LEGUMINOUS WINDBREAK IN CROP.
The spiral pattern allows a continual tractor path; it also provides a very sheltered crop environment for all wind directions.

HURRICANES (CYCLONES, TYPHOONS)

Very stable and still–air calms near the equator may produce fierce updraughts of air over warm oceanic areas, which over some days or weeks build up to the great rising spirals of hurricanes. As these move slowly (usually at 24–32 km/h) across the ocean towards land, wind speeds around the vortex can reach 128–192 km/h, while within the vortex itself a "tidal bulge" rises up to 2.7 m (9 feet) above sea level (**Figure 5.21**); this water bulge causes a tidal surge at coastlines.

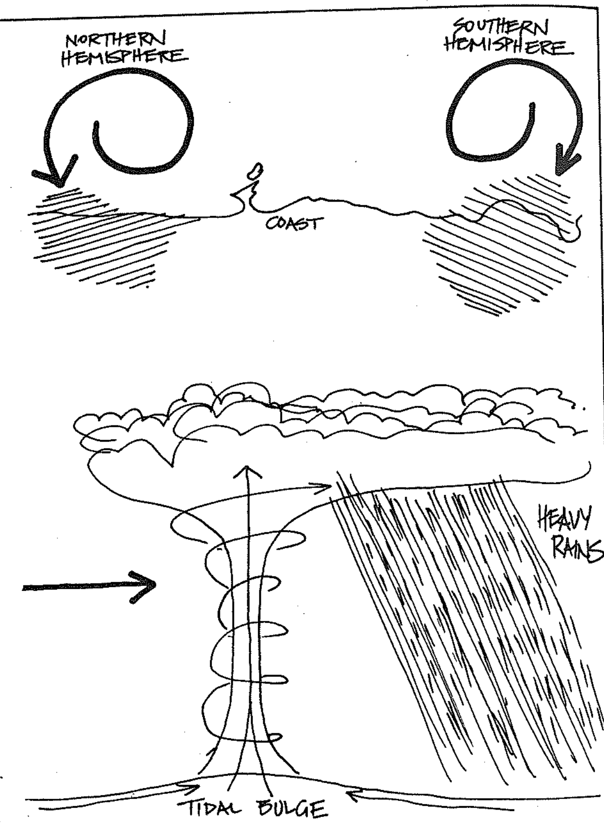


FIGURE 5.21
HURRICANES OR CYCLONES.
Rain and inshore, tidal effects are most severe to the poleward sides of the low–pressure cell, as is inland flooding, accentuated by the tidal bulge.

Vortices revolve anti–clockwise in the northern hemisphere, clockwise in the southern, and thus coastal areas to the north side have the highest water and wave levels in the northern hemisphere, and to the south side in the southern. The combined effects of rapidly fluctuating pressures, tidal bulge, wave and sea pile–up, and wave backwash create devastation on coasts. Although hurricanes cannot persist far inland, as the sea itself generates the vortex, the intense rains generated do reach well inland to flood rivers and estuaries, adding to the general destruction. With all effects combined in a "worst case" of high tides and prior rains, destructive wave attack can reach 6–9 m (20–30 feet) above normal high–tide wave levels.

As wind strength increases at sea, wavelength also increases, so that normal wave fronts arriving at 8 per minute in calm Atlantic conditions slow down to a storm frequency of 5 per minute before great winds. These wider–spaced waves travel fast, are larger, and create severe backwash undermining of shorelines.

Storm waves may therefore arrive long before a cyclonic depression or hurricane, and the change of wave beat gives warning to the shore crabs, birds, fish, and turtles, who either take shelter inland or go to sea to escape the approaching hurricane.

As modern satellite photographs are used to track the hurricane, there is usually a few days' warning for coastal areas, and evacuation is sometimes ordered. Well–built towns (such as Darwin, Australia, after its cyclonic devastation in 1972) can withstand cyclones with minimal damage, but such stoutness is usually only built in after an initial (and sometimes total) destruction. It is possible to strictly regulate and supervise buildings to be safe in hurricanes, and in areas where flimsy constructions are normal, to dig refuge trenches and caves for emergency shelter. All such shelter must be in well–drained hillside sites.

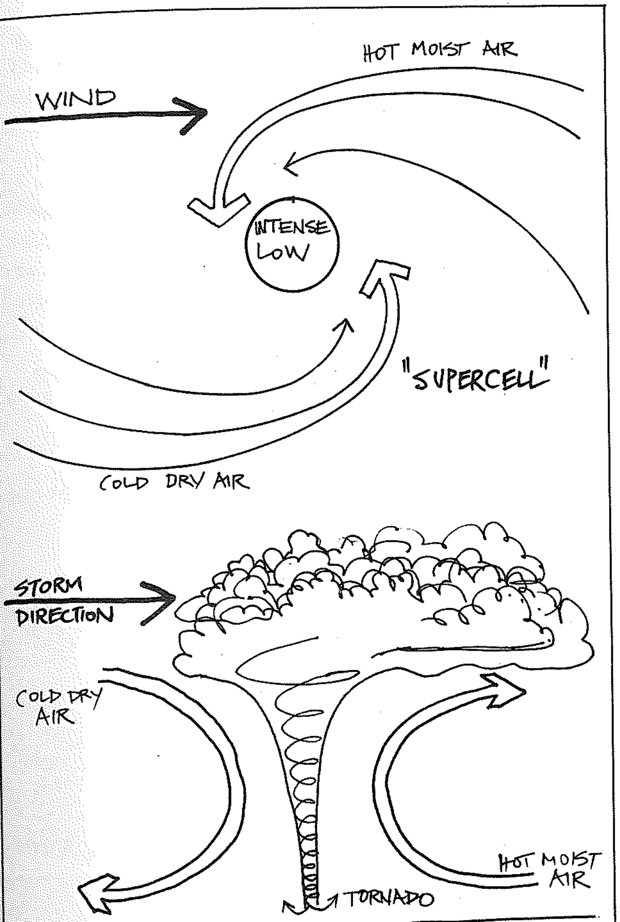


FIGURE 5.22
TORNADOES.
Unlike hurricanes, tornadoes occur over land and sea from shear effects at the junction of hat and cold air masses, creating intense low–pressure vortices.

TORNADOES

Hurricanes are large, slow phenomena covering hundreds of square miles, and mainly confined to coasts facing large stretches of tropical seas, with very large heat cells. Tornadoes, however, may occur in quite cold inland areas, last only seconds or minutes, and affect only a few square kilometres. Thus, they usually escape detection by satellite and ground sensors.

Nevertheless, the stresses placed on buildings, civil constructions, chemical or nuclear facilities, airfields and villages can be disastrous. Wind speeds may reach 120 km/h, at worst 280 km/h; these speeds can exceed hurricane winds. The conditions for tornadoes are:

- Thunderstorms with fast–growing cumulonimbus cloud;
- A persistent source of warm moist air to feed the updraught side of the front;
- An input of cold dry air entering the system from another direction; and
- A vortex formation in the resulting storm; this reaches the ground as a tornado, caused by wind–shear effects at the border of the conflicting system, or as a frontal dust storm in deserts.

Effects: Trees twisted off and broken; people and

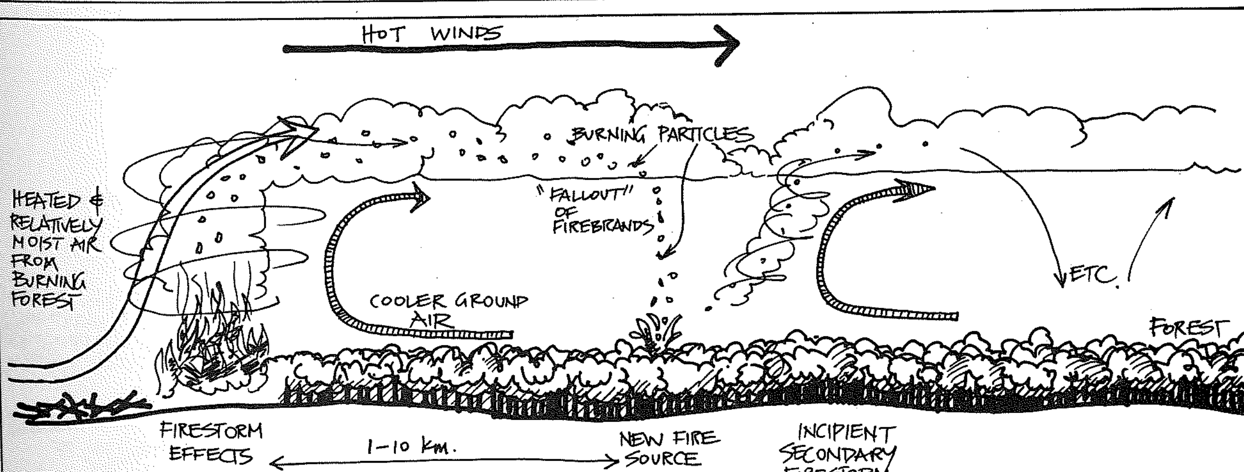


FIGURE 5.23
FIRESTORMS.
Wildfire can create fire tornadoes, especially at hill crests, and these spread burning particles downwind for many kilometres.

objects sucked out of cars and buildings; "rains" of soil, fish, frogs may fall out ahead of the disturbance.

FIRESTORMS

Intense wildfires (urban and rural) fanned by dry winds will create powerful vortices due to conditions very much like that of the tornado. The mass ignition of large areas of forests and buildings feed a powerful updraught. Colder dry air rushes in to replace the air consumed in burning, and fire tornadoes (firestorms) result, carrying large burning particles aloft on "smoke nimbus" clouds. Whole house sections pinwheel across the sky to drop out ahead of the main fire front, where they in turn set up secondary firestorm conditions. The effects on people and property are very much like those of tornadoes, but with the additional danger of intense heat.

5.7

LANDSCAPE EFFECTS

CONTINENTAL EFFECTS

Heat is transported on a world scale by two great circulations: that of the air masses, and those of oceanic currents. Of these, air masses are more wide-spread in their effect, and are least limited by land masses. Oceanic currents, or indeed proximity to any large body of water, have their greatest moderating effect on down–wind shorelines. Such effects may have little inland influence. The concept of continental climates was evolved to describe those extreme and widely fluctuating inland climatic zones that are not buffered by the effects of sea currents, and which demonstrate periods of extreme heat and cold, all the more marked on high mountains.

Thus, the third complication on the simple temperature–rainfall classifications is CONTINENTALITY. After this, only one special factor remains, and it is the effect of hills or ranges of mountains on local climate; these effects are very like the latitudinal effects on a global scale.

LATITUDE AND ALTITUDE

An average measure of temperature fall with altitude is: 9.8°C/km (5.4°F/1000 feet) in rainless or dry air; or 4–9°C/km (2.2–5°F/1000 feet) in humid and saturated conditions.

As a rough approximation, every 100 m (330 feet) of altitude is equivalent to 1° of latitude, so that at 1000 m (3300 feet) on the equator, the temperatures are about equivalent to a climate 10° off the equator with the same humidity. At 10° latitude off the equator, a plateau at 1850 m (6000 feet) has a climate more like that at 30° latitude, with a probability of wind chill to below freezing. For high islands or ranges of mountains, this altitudinal factor is crucial to design strategies for homes and gardens. Altitude effect alone enables us to grow a wide range of plant species on a high island, using the area from ocean to mountain– top.

<u>High Altitude Effects</u>

Mountains are not in fact strictly "latitude equivalents", as the air is more rarefied, air pressure less, and radiation therefore higher. On very high mountains of 4000 m (13,000 feet) and more, people may experience oxygen deficiency (mountain sickness), snow or radiation blindness, and suffer from the extremes of day–night temperature fluctuations. The mountain sickness of oxygen stress is not felt by locals, but can cause extreme fatigue, insomnia, and laboured

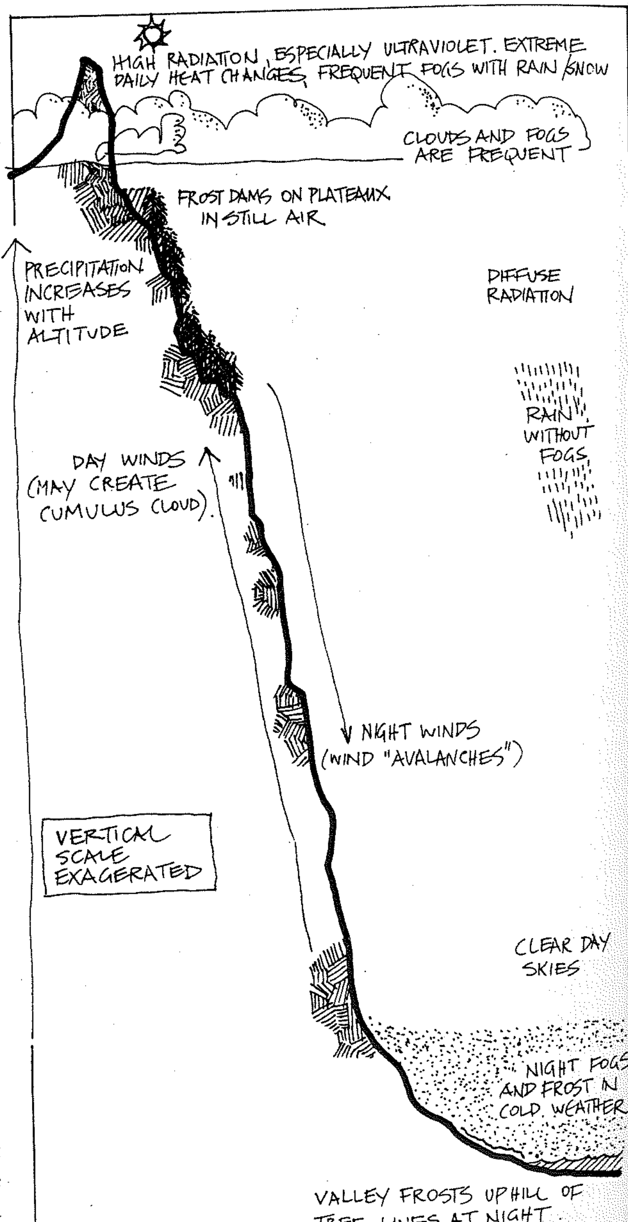
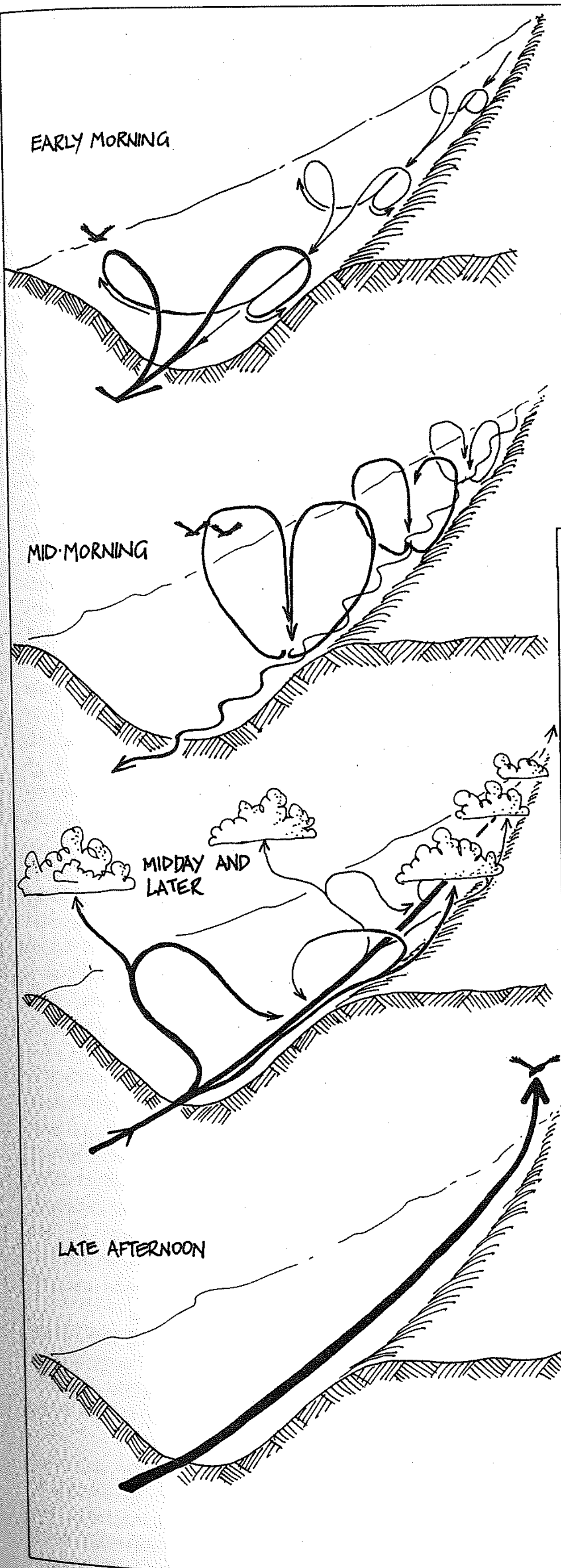


FIGURE 5.24
HIGH ALTITUDE LANDSCAPE.
Local effects may mask or eclipse wider climatic conditions in mountainous regions.



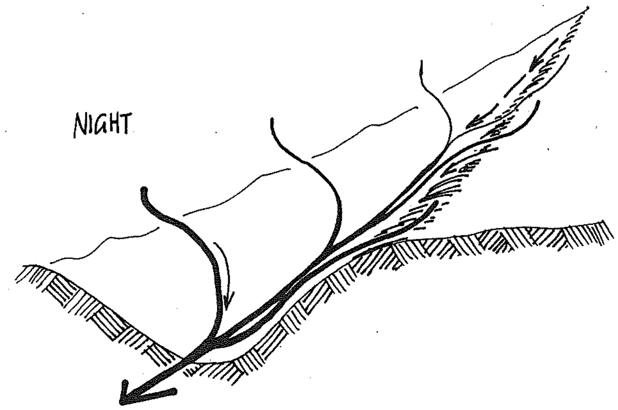


FIGURE 5.25
VALLEY WINDS
These follow a daily cycle. Many bird species use these winds to follow a daily migration (downhill at dawn, to ridge forests at evening). Both wind and temperature effects are local.

breathing in visitors. In the Peruvian Andes, day temperatures remain at 16–19°C (61–66°F) all year, but night temperatures fall rapidly to –10°C (14°F). Shade temperatures are lower than at sea level, due to the less effective heat transfer and insulation effects of the rarefied air. Water boils at lower temperatures due to the low atmospheric pressure, and snow may sublime directly to water vapour rather than melting. High mountains reduce the range of foods available.

Snow cover may serve as an insulating blanket, and prevent early spring thawing, or even autumn freezing if it covers unfrozen ground. Snow cover also causes intense reflection, and raises air temperatures just above the snow by day. At night, radiation from snow causes an extremely cold ground air layer, so that any plants protruding from snow suffer these extremes of diurnal temperature.

As great as the effect of altitude is, the effect of slope is even more pronounced. Daubenmire (1974) records that slopes of 5° towards the poles "reduce soil temperatures as much as 168 km distance" towards the poles, so that even a gentle slope away from the sun creates very much cooler conditions locally. The effect of cold ravines in near–permanent shadow is extreme indeed, and one may stand in hot sunlight in the Himalayas and gaze into icy depths where only the hardiest life forms exist, and where ice may permanently cover rocks and spray zones caused by waterfalls or rapids.

VALLEY CLIMATES

We have referred to the chill of narrow, shaded, high altitude gorges, but an opposite effect occurs in sun–facing wider valleys, sheltered from winds. Here, hot air builds up rapidly, soils are drier, and strong winds may be generated (upslope and up valley by day, downslope and down valley at night). **Figure 5.25** demonstrates this effect in moderate mountain areas of

3,000–4,000 m (9,850–13,000 feet).

In large valleys, and especially in cool moist climates, the upslope wind may result in the generation of a chain of cumulus clouds at the valley head, trailing off as a succession of clouds from mid-morning to evening. In more tropical humid climates, the cloud may be continuously held on the mountain tops; this forms part of the standing cloud of high islands. Such cloud (and rainfall) effects are accentuated by forest on the valley sides and ridges, as trees actively humidify the air streams by transpiration in hot weather.

Valleys in tundra and desert support tree populations absent from the plain or peneplain areas surrounding them, but the reasons may differ in that tundra valleys are likely to be protected by (driven) deep snow cover. This preserves warm or sub-lethal soil temperatures in winter (as well as providing excess summer melt moisture). Valleys in deserts remain moist due to the deep detritus which fills their floors; the shaded soils lose less moisture to evaporation. Lethal soil temperatures are also avoided by partial shading. Both ice-blast and sand-blast are modified or absent in valley floors, so that unprotected seedlings can survive high winds in the shelter of valleys.

Thus, valleys (or wadis) are preferred growing sites in deserts, and provide tree products in otherwise treeless tundras, although the latter sites are rarely occupied by human settlement.

In the field, we often notice a sudden coldness just before dawn in valley areas; this is the time of the greatest depth of cold air, and hence the greatest intensity of cold. Air flowing down from the mountains has pooled all night, and just before the sun rises, we (and many animals) are at our greatest exposure and lowest ebb. It is at this time that winds off glaciers flowing down cold valleys reach their maximum speed.

Without wind or air flow, radiation frost can form, as it does in sheltered hollows and tree clearings. In these areas, opening up the clearings or draining them of cold air may help reduce frost, if that is the aim (**Figure 5.13**).

When, some years ago, I grew such crops as tomatoes and cucurbits inside open tree canopies, I did prevent frost, but lost crop due to low light levels and a lack of wind or insect pollination. In such cases, a shade-side screen of reflector plants facing the sun would help to keep light levels up, and plants to attract bees need to be placed around the clearing. Arboreal or ground browsers within forests are also worrisome in gardens (possum and porcupine for example). Green-leaf vegetables, however, are not usually eaten, and can be successfully grown in small forest clearings or in open forest in frosty areas.

5.8

LATITUDE EFFECTS

Despite the weak light and short growing season at high (sub-polar) latitudes, the very long summer days provide more than a sufficient quantity of light for vigorous plant growth. The daily total for late summer (July) is 440 Langleys at Madras, India (13°N); 680 Langleys at Fresno, California (36°N); 450 at Fairbanks, Alaska (64°N). The average radiation in temperate areas is 1–5 times that of the tropics (Chang, 1968).

This is accentuated, on or near coasts, by the moderate temperatures from the convection of air over warm currents in such areas as Alaska and the northwest coastal regions of Europe. The benefit of these areas is that the generally lower temperatures, which suit photosynthesis, confer a photosynthetic efficiency that makes a considerable production of cereal, berries, tomatoes, potatoes, and vegetable crops tolerant of short season/long day conditions. The often deep periglacial soils provide the basis for the production of gigantic lettuce, cabbage, spinaches, and root crops, so that these areas are very favourable for agriculture in summer.

Such conditions prevail in Alaska, Ireland, Scotland, and parts of Norway. Shelter and added nutrients from seaweeds and manures yield rich meadows and heavy vegetable production during the long summer days. The small stone-walled fields of Ireland produce abundant sweet hay, root crops, and greens for storage during winter.

Conversely, the ample light at low (equatorial) latitudes is inefficient due to the extremely high temperatures there, and the excess light may mean that plants are light saturated. Photosynthesis may actually decline in the intense light, and the energy built into the plants may be less in sunlight than in partial shade. Shade (down to a level of 20% sunlight) is of great benefit in tropical deserts and sunny equatorial climates. Trials of shadecloth with 50–70% light transmission may greatly increase plant bulk and production, e.g. of sugar beet, thus the importance of tree shade and shadecloth in deserts and cleared-area tropics.

Similarly, temperatures above 25°C (77°F) sharply decrease photosynthetic efficiency, so that the normal desert or equatorial condition of high light and temperature is very inefficient for the production of plant material. In the arctic or high latitudes, 15°C (59°F) is *optimum* for adapted species and cultivars, and 20–24°C (68–75°F) for many useful food plants. Tropics are noted for a low production of those crops which can be also grown in temperate areas; light shade may be the essential component for increased yields.

In bright sunlight, leaf temperatures often exceed air temperatures, so that the diffuse light of overcast or cloudy days in high latitudes helps plant growth, especially after midday as temperatures would then also rise above optimum in direct sunlight.

Photosynethetic efficiency is limited by the ability of the leaf to obtain carbon dioxide or by low levels of available carbon dioxide. At high light intensity, we need to supply carbon dioxide (to the saturation level of 0.13% to obtain a 2–3 times increase in photosynthetic rate. Carbon dioxide can be supplied by composting or by housing animals in greenhouses where light is more than sufficient.

It follows that the summer periods of the high latitudes are ideal for biomass production, while equatorial regions evolve biomass mainly as a result of a year–round (inefficient) growth and perennial crops. The ideal of steady low light/low temperature conditions may be at times achieved below the closed forests of tropical mountains, but these sites are very limited in extent, and carbon dioxide concentration is also low. Rice, for example, yields 4–5 times better in temperate areas than in tropical ones, although up to three crops per year in the tropics helps to increase local yields over the year.

It should be feasible to assist tropical crop yields by spacing permeable–crowned trees throughout crops to reduce both light and temperature, e.g. using *Prosopis* trees with millet crops in India, or partially–shading taro in Hawaii. Grass growth in temperate areas also increases with shelterbelt, but this may reflect the *warmer* conditions and lack of mechanical wind damage that such trees as tagasaste provide. Trials of light–transmitting or thin–crowned palms and legume trees would quickly show results, and there are a good many observations to suggest that (if water is sufficient) crops under leguminous trees do much better in the tropics than a crop standing on its own.

Part of the problem in tropics (both for biomass production and nutrition) is that non–adapted temperate crops are persistently grown there. True tropical plants can not only stand much higher levels of light before saturation, but can also maintain photosynthesis at low (0.10%) carbon dioxide.

In summary, we do not have to accept the climatic factors of a site as unchangeable any more than we do its treelessness or state of soil erosion. By sensible placement of our design components, we can create myriad small differences in local climatic effects on any site. In the technical field, we can create useful conversions of energy from incoming energy fluxes such as wind and sun, and produce energy for the site. In the patterning of a site with trees, ponds, earth systems, or hedgerows, we can actively moderate for better climatic conditions, or to eliminate some local limiting factor.

5.9
REFERENCES

Chang, Jen–Hu, *Climate and Agriculture,* Aldine Pub. Co., Chicago, 1968.

Chorley, R.J. (ed.), *Water, Earth, and Man*, Methuen & Co., London, 1969.

Cox, George W., and Michael D. Atkins, *Agricultural Ecology*, W. H. Freeman & Co., San Francisco, 1979.

Daubenmire, Rexford F., *Plants and Environment*, Wiley International, 1974.

Eyre, S. R., *World Vegetation Patterns,* Macmillan, London, 1971.

Gaskell, T. F., *Physics of the Earth*, World of Science Library, Thames & Hudson, London, 1970.

Geiger, Rudolf, *The Climate Near the Ground*, Harvard University Press, 1965.

Holford, Ingrid, *Interpreting the Weather*, David & Charles, Newton Abbot, UK.

James, P. E., *Outline of Geography*, Ginn & Co., Boston, 1941.

Trewartha, S. T., *An Introduction to Climate*, McGrawHill, New York, 1954.

Twidale, C. R., *Structural Landforms*, Australian National University Press, Canberra, Australia.

Staff of the L. H. Bailey Hortorium, Cornell University, *Hortus Third: a concise dictionary of the plants cultivated in the United States and Canada*, Macmillan Publishing Co., 1976.

5.10
DESIGNER'S CHECKLIST

Check data on average rainfall, temperature, and wind speed and direction for the region (often found by contacting the Bureau of Meteorology).

Ascertain the general "hardiness" zone for plants and animals. This is based on temperature, with frost being the limiting factor. Make a survey of the plants that grow in the area, noting special circumstances surrounding plants that are "marginal"; what is the technique or microclimate that allows them to grow?

Find out about flood locations and periodicity, rain intensity, temperature extremes, and the *seasonal* rainfall pattern. Allow for extremes (e.g. no rain in summer) when designing.

Consider *total* precipitation (snow, hail, rain, fog, condensation, and dew) so that your design can include ways to trap and store moisture (dry climates) or ways to dispose of too much moisture (wet climates).

Consider *light availability*, especially on foggy coasts; light becomes the limiting factor for flowering plants.

Continental climates mean more temperature extremes, while maritime climates buffer severe heat or cold.

Altitude effects: approximately every 100 m of altitude is equivalent to 1° of latitude, so that a variety of plants can be grown if the property contains hills and flats. In the sub–tropics, even temperate–area plants can be grown on high islands or hills.

Note where frost is produced (in hollows, on flats, and in large clearings) and where it is absent (the "thermal belt" on hills, under tree canopies).

Note tree flagging on the site; this shows the direction of *persistent* winds (although winds, sometimes severe, may blow from other directions). You can put tall stakes with coloured cloth or plastic streamers at different locations and observe them seasonally. (**Figure 6.2**).

For accurate temperatures, you can have several maximum/minimum thermometers in different locations. These thermometers record the highest and lowest temperatures reached during 24 hours, and are helpful in locating microclimatic areas such as thermal belts (if on a sun–facing slope), cold drainage areas, frost hollows.

Site house and garden on the thermal belt if possible.

In minimal–frost areas, plant light–canopy trees *in* the garden for frost protection (tree canopies help keep rapid cooling of the earth to a minimum). Or plant into a steep–sided clearing or pit.

In houses, design so that you use light and radiation to best effect, particularly in temperate climates. Particular use should be made of the thermosiphon effect of heat, so that heat sources are placed below storage and use points.

Use the principle that white reflects, dark absorbs, heat. Plant shrubs and trees needing heat and light in front of white–painted walls.

When planning windbreaks, consider:

- Trees that give multiple function, e.g. mulch (*Casuarina*), bee nectar (dogwood), sugar pods for animals (carob, honey locust), edible leaves (*Leucaena*, tagasaste), berries for poultry (*Coprosma repens*, Russian olive).
- The windbreak planting itself may need initial protecion and care (nutrients, water, weeding, or mulching).
- If the winds are *very severe*, look around the area to see what stands up to it, and plant it whether it provides multiple function or not. Plant more useful plants in its lee. Protection includes fencing, earth banks, tyre walls, etc.
- Choose a windbreak configuration that is effective for the particular design situation. In tropical and subtropical areas, a thin–crowned windbreak in crop can be used to advantage, providing shade and mulch for vegetable crop.