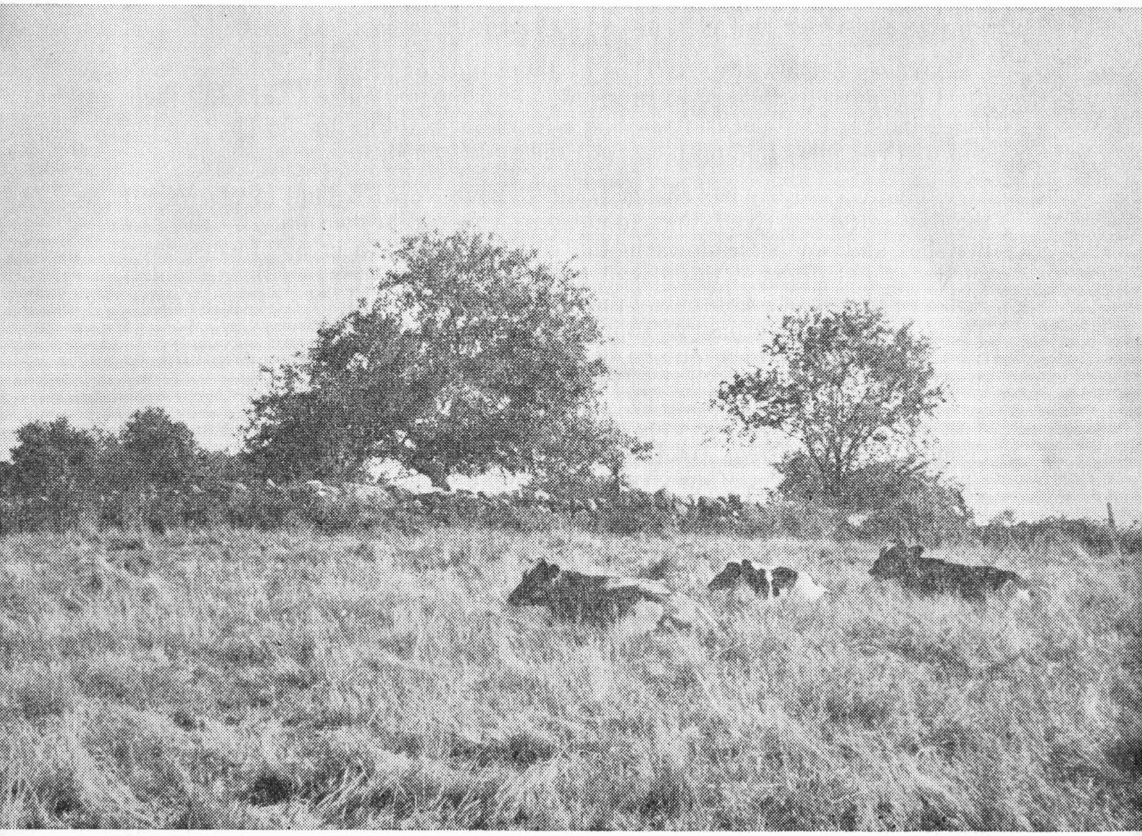
Plants, Shade, and Shelter

Paul E. Waggoner



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Foreword

In this Bulletin the reader will find a scientific study of microclimates, the peculiar and small climates of particular places in which many Connecticut people live, shop, and play. Some of these microclimates have been changed by man, others have been unchanged for centuries. Our interest in microclimates, artificial or natural, is directly related to our present-day mobility. Henry Ford put the nation on wheels, and now we live and work and play in widely separated areas.

It was not always so. Tens of thousands of New England workers lived out most of their lives in a few microclimates indeed, carrying their lunch pails a few blocks from home to factory, riding to the park at the end of the trolley line on pleasant Sunday afternoons.

That way of life has changed, and so have New England farms. When the first settlers arrived, they found virgin forest, broken only by the salt marshes and small meadows in the river valleys. To create farms, they cut trees and dragged the glacial boulders into the stone walls of which Robert Frost sings. Ultimately they cleared more than half of Connecticut. Their agricultural economy supplied most of their needs for food, and they exported potatoes, onions, meat, and tobacco to New York and to the West Indies.

It has been a long time since Connecticut farms fed Connecticut people. Now our cows are fewer, but they give three times the milk that Colonial cows gave. Our fruit, poultry, tobacco, and vegetable farms produce likewise, and still we rely more and more on the fields and orchards of the West and the South. Modern transport ties the nation together, releasing much of our land from farming.

Thus many of the fields once plowed or mowed have become thickets. As more and more people come to live in Connecticut, fields and woodlands have become developments, filled with houses and children and ranch wagons. With the people have come shopping centers, outdoor movies, and multi-lane highways, occupying land once farmed. Cottages and year-round residences line our Shore and surround our lakes. Hundreds of thousands live in the country.

At least it used to be called the country. In this new country living, citizens complain if the school bus is late or the driver is surly, they get fuel oil deliveries within the hour after calling, and they expect $50,000 worth of fire-fighting equipment to arrive in minutes to quench a smoldering TV set.

These newcomers to the Connecticut countryside, these exurbanites, have time and money to spend in their new microclimates of old field or woodland. Within limits, they can create microclimates that suit them, at least part of the time. The study here reported may help them understand the natural laws that define what can be done, and what cannot.

W. L. Slate
Station Director Emeritus

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Cover Photo

The pasture, one of seven sites where microclimate was studied.

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The migration from city and farm to the suburbs has caused homes to rise and lawns to spread across fields where corn or hay grew only last year. Or, as in so much of New England, where the farms were forsaken and the hills were last cleared a generation ago, the new lawns are clearings in a thicket of briars, honeysuckle, and trees struggling to make a forest. The immigrants to either the fields or the thickets both encounter extreme microclimates: Some of them find no trees to shade them, the others are smothered in their shelter. In this Bulletin we shall describe the climate and comfort of seven sites: the pasture and its shade tree, the thicket and its clearing, the beach, the lawn, and the parking lot.

The common indicators of climate and comfort, the temperature and humidity, differ very little among these sites and their microclimates. This perplexes the inhabitant, who surely feels a difference.

The perplexity arises because the thermometer in its louvered Weather Bureau shelter passively follows the temperature of the air, while the man's body strives to maintain an unchanging temperature. More, or less, heat is produced inside the man as he exerts himself more or less. If he is to be comfortable, this heat must be nicely balanced against several variable streams of heat that are entering and leaving the human system. If these are not balanced, his temperature will rise or fall, leaving him feverish or chilled. Thus comfort is determined not by the temperature of the air but by whether the man must sweat or shiver to balance several streams of energy and maintain his temperature unchanged.

How much he exerts himself and, hence, how much heat he generates is his affair. How much clothing he wears is also for him to decide. Our business is measuring the streams of energy in each site and presenting for each site the number of calories of heat that a lightly clad man could lose without sweating. We must also integrate the streams of energy in terms of the loss from a man who is soaked with sweat. If the weather is hot, or the work is heavy, the site with the greatest potential for loss will seem coolest and most comfortable. If the weather is cold, or the worker rests, the site with the smallest potential will seem warmest and most comfortable.

Calories are gained and lost via four routes. The first two are two sorts of radiation. Because radiation is given off in wavelengths and amounts fixed by their temperature, the incandescent sun emits radiation of relatively short wavelengths. This is the first route for calories. We call it sunlight, for much of its energy has waves so short that they are visible. We see it blocked and call the barrier "shade." For a man or tree, the sun's short-wave radiation is a one-way route of gain without loss.

The second channel for calories is also radiation, but its waves are long and invisible, for the radiators are relatively cool. It is a route of both gains and losses, for these long waves are the ones emitted by objects that have the temperature of man or tree. The amount given off is according to the temperature of the object.

A man gives off these long waves, while he receives others from everything about him. Thus, in the summer he feels the heat from a hot black pavement, and in the winter he feels a cold window. He is absorbing much long-wave radiation from the hot summer pavement and little from the cold winter window. Within sight of the window he wants shelter because he suffers a net loss by long-wave radiation, and the loss must be made up somehow.

The two remaining routes for calories are convection and evaporation. Convection is easily visualized: as cool air passes about the man and is warmed by his skin, calories are carried away from the man and into the atmosphere. Evaporation, the remaining route for calories leaving the man, can also be pictured: perspiration wets his skin, calories are taken from him to change the liquid into gaseous water, and this vapor is removed from his neighborhood by a turbulent atmosphere.

Here the two common indexes, air temperature and humidity, are useful indicators of comfort. The cooler and drier the air, the more calories will be carried away via convection and evaporation. Even here, however, air temperature and humidity will not serve alone, for ventilation as well as cold and aridity speed the losses. Thus when shelter stills the wind, it slows the loss of heat via convection and evaporation. Then they contribute less to the sum of themselves and radiation, and thus, the losses and comfort of the man are changed.

Since shade or shelter has most effect, and to us most significance, when the sun shines or the evening sky is clear, our observations were taken under unobscured midday sun or a cloudless evening sky. These conditions were most easily encountered in the autumn. Thus on September 20 through October 2, 1962, we collected the observations of radiation and ventilation, temperature, and humidity. From these nearly ideal conditions we shall surmise how the shade and shelter of plants might affect a man's loss of heat and, hence, comfort on a hot day or a cold evening.

The Sites

On Sachems Head, a projection of the Connecticut coast into Long Island Sound, idealized sites were found, and the landowners, Milton and Edwin Benton, kindly permitted us to carry cables and radiometers through their woods and pastures. The *pasture* site, in the background of Fig. 1, is on a knoll, 50 feet above the Sound which lies one-third mile to the south. Between pasture and Sound is a salt marsh as well as low fields where blueberries abound. In the other directions are hills covered by second-growth woods; the pasture extends several hundred feet, however, before the woods are reached. The native grass was not closely cropped and much was ripe and dry. Nevertheless, most of the grass was still green and formed a mat not more than 3 inches deep.

Along the ridge about 60 feet from the pasture site stands the *apple tree,* Fig. 1. It is 15 feet tall. Its crown is 25 feet across, and

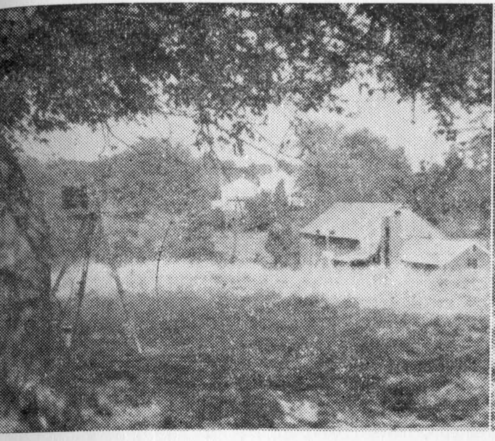

Figure 1. The apple tree.

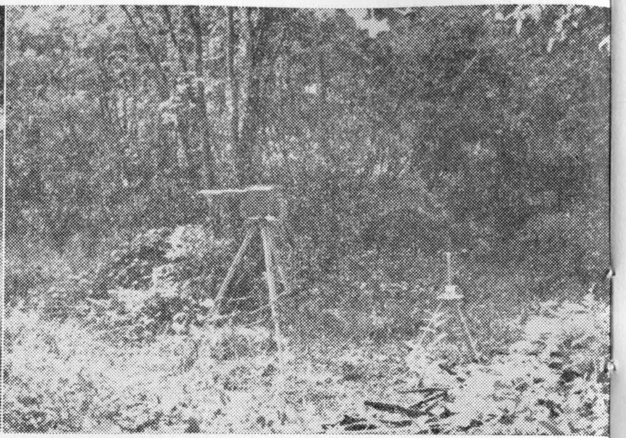

Figure 2. The clearing in the thicket.

beneath, it has been browsed to 6 feet. Cows enjoy its shade and fruit and have trampled the grass beneath. In the autumn much of its shadow does not fall beneath the crown, for the sun is low in the sky; thus one can stand in its shade but beneath the open sky. Twenty-five feet west of the apple tree is a 3-foot stone wall which separates one pasture from another (Cover photo).

Near sea level and 800 feet to the southeast lies the *clearing* in a thicket of red maple, tulip tree, speckled alder, black cherry, briars, and grape vines (Fig. 2). The clearing is 25 feet in diameter. The screen is thinnest to the southeast, the direction of the salt marsh. On the floor of the thicket, a sparse growth of briars had appeared, and it was cut before observations began.

In the *thicket* a few feet away, observations were taken among a tangle of briars and saplings. Where dim light fell upon the damp ground, jewel weed grew. Overhead, maple and grape leaves covered the view (Fig. 3).

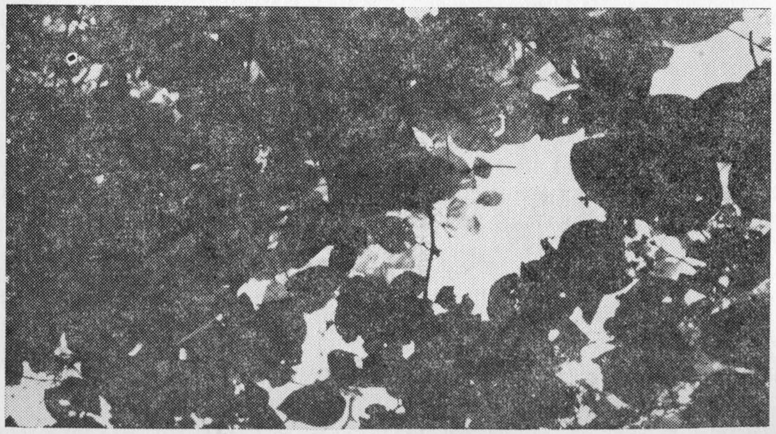

Figure 3. The tangle above the radiometer in the thicket.

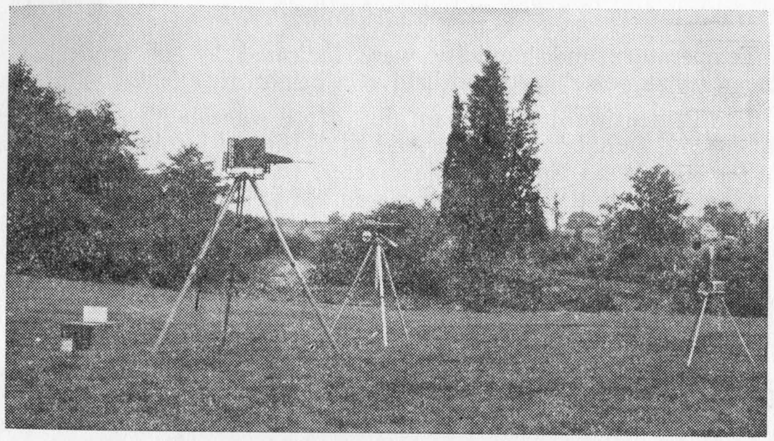

Figure 4. The lawn with the salt marsh and Sound beyond.

Between pasture and thicket is a *lawn* of nearly an acre, well watered and mown (Fig. 4). Few tall plants hinder the breezes from the Sound.

On the *beach* observations were taken above a level stretch of sand that had nearly dried after the tide had receded (Fig. 5). A few feet away, enclosed on three sides by *reeds* 6 feet tall, is a 20- by 25-foot patch of dry sand.

Behind the 5-foot dune that forms the beach and supports tall reeds is the salt *marsh* (Fig. 6). It is covered with the low grass and other plants that tolerate the salt water which wets the muck beneath. These plants were bent into a reddish-green mat about 3 inches thick. Beneath the mat, water stood on the soil and squished under foot.

The *parking lot* is inland, 3 miles from the other sites. It is paved with asphalt, and surrounded on two sides by a supermarket and houses.

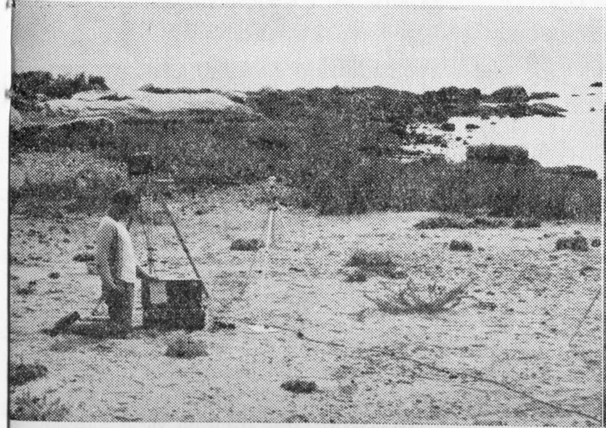

Figure 5. The beach.

Figure 6. The salt marsh.

The Instruments

Temperature and humidity were indicated by an aspirating psychrometer that was shaded and held at a height of 3 feet.

The R, density of the radiant flux of all wavelengths, was indicated by a Gier and Dunkle[1] radiometer and S, density of insolation or radiation from the sun, by an Eppley pyrheliometer. These meters are planes, and the radiation from the upper and lower hemispheres was observed separately, by directing the meters first upward (u) (Fig. 2) and then downward (d) Fig. 4). The direct insolation was estimated as $0.9S_u$, the scattered insolation and long-wave radiation from the upper hemisphere as $0.1\ S_u + (R_u - S_u)$, and reflected insolation and long-wave radiation from the lower hemisphere as S_d and $(R_d - S_d)$.

Wind speed was indicated 3 feet above the ground by anemometers made by Mr. William Wright. The dimensions were approximately those of an airways Weather Bureau anemometer, but the cups were thin plastic, the arms were slender aluminum rods and the counter was actuated when a small magnet in the hub passed above a proximity switch. The bearing was a metal point on which a glass hemisphere hung and turned. In the field, the four anemometers agreed within 3 per cent. In a steady draft in the laboratory, the anemometers were calibrated by means of a Velometer (Illinois Testing Laboratory, Chicago). Wind speed was measured more or less simultaneously by anemometers at each site, while the other factors were measured sequentially as I carried instruments from site to site.

Analysis

If a man is not to become cooler or warmer than normal, his metabolic heat and his receipt of solar radiation must be balanced by net exchange through long-wave radiation between him and his environment, by convection, and by evaporation. All of these streams of energy that enter and leave the human system have been described in the Introduction. Now they must be reduced to equations that will accept our numerical data.

Accordingly we write the exchange of energy with the environment as the sum:

Solar radiation + Long-wave radiation + Convection + Evaporation

During a midday hour, solar may add 150, long-wave radiation add 250 and subtract 400, convection subtract 200 and evaporation subtract hundreds of kilogram calories from each square meter (kg cal m^{-2} hr^{-1}). Small wonder that temperature and humidity alone do not reflect the "feel" of an environment or a microclimate. Our observations of the several factors are, therefore, integrated by an estimation of the net loss of energy.

This estimation requires a description of the man who experiences the losses because the warmer his skin and the more he sweats and the thinner his clothing, the more heat he loses. Since our primary interest is analysis of microclimates and not of men, we shall specify a standard man and move him from one microclimate to another, estimating his loss of energy in each. Although he will be ill-clad in some, his energy exchanges in all will reveal the significant differences among the environments. The following generally follows Buettner[2].

The man is clad only in shorts. His skin has a temperature of 33 C (91 F). He presents an area of 1 m^2 or about 1 square yard for the exchange of radiation with his surroundings, for the convection of the atmosphere, and for evaporation. For the receipt of the direct sun beam he presents only 0.25 m^2, but for the scattered and reflected sunlight he presents fully 1 m^2. He absorbs 0.65 of the insolation and 0.96 of the long-wave radiation which reaches him. We assume that the sum of the scattered and reflected solar and of the long-wave radiation from the two hemispheres that warms the radiometer plates indicates the radiation that warms the man. He emits 0.96 as much radiation as a perfect radiator that is as warm as his skin; thus he emits 414 kg cal m^{-2} hr^{-1}.

The gain of solar radiation is, therefore,

$$0.9\ S_u \times 0.65 \times 0.25 + 0.1\ S_u \times 0.65 \times 0.50 + 1.0\ S_d \times 0.65 \times 0.50;$$

the gain of long-wave radiation is

$$1.0\ (R_u - S_u) \times 0.96 \times 0.50 + 1.0\ (R_d - S_d) \times 0.96 \times 0.50,$$

and the radiation emitted by the man is 414 kg cal m^{-2} hr^{-1}. The loss by convection is $1.2\ v^{1/2}\ (t_s - t_a)$ kg cal m^{-2} hr^{-1} where v is wind speed in centimeters per second (cm sec^{-1}), skin temperature t_s is 33 C and t_a is air temperature. (A 1 mile per hour breeze is 45 cm sec^{-1}). When the man is dry he will lose little by evaporation, but when he is wet with sweat he loses

$$1.63\ v^{1/2}\ (e_s - e_a) \text{ kg cal } m^{-2}\ hr^{-1}$$

where e_s and e_a are the vapor pressures (millibars) of the wet skin (50.1 mb) and of the air.

The net loss is the algebraic sum of emission, convection, and evaporation less the gains via solar and long-wave radiation.

As warned above, the man will be ill-clad for autumn evenings and even some days. For example, to balance the loss of 474 by a dry man in the pasture on the evening of September 21 would require the heat generated by brisk walking. This loss could easily be reduced by clothing. One unit of clothing maintains comfort when one is seated at 21 C (70 F), usual room temperature[3]. This clothing would reduce the loss from 474 to only 126, which equals the heat generated when one is merely working at a desk.

To balance the losses incurred by a wet man on the same evening would require exertion that would soon exhaust him. Nevertheless, the losses estimated for a lightly clad man in the different environments reveal the difference among them. This is our objective, and we turn to the data.

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[1] Gier, J. T. and R. V. Dunkle. 1951. Total hemispherical radiometers. Proc. A. I. E. E. 70:339-343.

[2] Buettner, K. J. K. 1951. Physical aspects of human bioclimatology. *In* Compendium of Meteorology, T. F. Malone, ed. Amer. Meteor. Soc., Boston. pp. 1112-1114.

[3] Winslow, C. E. A. and L. P. Herrington. 1959. Temperature and human life. Princeton Univ. Press. p. 136.