ENERGY SAVING CONCEPTS APPLICABLE TO LANDSCAPES

The goal of all contemporary building design, whether it falls under the heading of architecture, landscape planning, or interior decoration, is to increase human comfort and reduce energy needs for space heating and cooling. The physical strength and mental activity of all people are improved within a specific range of climatic conditions. Outside this comfort zone, efficiency plummets; discomfort, stress, and the threat of disease increase.

There is a slight variation in the perception of comfort, either because of inherited or cultural characteristics. Most women choose a temperature a few degrees warmer than do men, young people prefer a temperature a few degrees cooler than do the elderly, and Eskimos thrive in a cooler climate than do Africans. But there are accepted, worldwide standards for human comfort.

This article analyzes the sensation of comfort and describes how the great climatic forces—sun, wind, and precipitation—affect it. It also demonstrates how plants may enhance comfort while reducing energy consumption.

The four factors that affect human comfort are: the energy contained in objects that radiate heat, the temperature of air, its movement, and humidity. Precise definitions of each are needed to understand how they influence comfort.

Heat, which is a form of energy, is distinguished from temperature, which is a measure of how much energy is stored. For example, two freshly poured cups of tea, one half-full and the other filled to the brim, are the same temperature. But the full one contains more heat energy. Different materials require different amounts of energy to be raised to the same temperature. "Specific heat" refers to the energy needed to raise a given volume of a substance by one degree Fahrenheit. The higher a material's specific heat, the more heat it holds, and the longer it takes to cool down. For example, air has an extremely low specific heat and heats up rapidly; metals such as gold and lead have higher specific heats. Water has a very high specific heat; it takes a lot of energy to reach a certain temperature, acts as an excellent reservoir of heat, and releases a lot of heat when cooling down. This is why large bodies of water such as lakes and oceans have a pronounced effect on climate. They heat up and cool down slowly, and moderate extremes of temperature.

Heat energy itself can be transferred by four methods: radiation, conduction, convection, and changes of state. Heat always travels from warmer to cooler substances, attempting to remove temperature differences.

Radiation transfers heat in space from object to object. It requires no contact between the object emanating the heat and the receiving substance and may take place in a complete vacuum. Radiation is responsible for the heat you feel when you stand in front of a fireplace or lie on a beach and soak up the sun's energy. Radiant heat can be collected from the sun independent of the air temperature. A sun-filled room collects radiant heat and warmth through a window, even in midwinter. Conversely, at night heat energy that has been absorbed during the day will be reradiated back into the sky and lost, if it is not blocked. In arid regions that have cloudless nights there is the potential for enormous radiational cooling at night. In cities, however, the low overhead smog often prevents nighttime radiational cooling. Radiation can be blocked by opaque barriers such as walls, heavy drapes, or plants with dense foliage; it can be filtered by translucent objects such as clouds, light shades, or vines on trellises.

In contrast, conduction transfers heat by direct contact. It is responsible for the heat you feel when you touch a hot iron or press a hot-water bottle to an aching part of your body. Conduction of heat away from the body produces the shivering sensation following a plunge into a cool swimming pool. Blocking conduction is more difficult than blocking radiation and requires specialized insulating materials with air cells that inhibit heat transfer such as wood, wool, polystyrene foam, rock wool, or thermopane windows.

Convection is similar to conduction, but it conveys heat in movable, fluid media, including air and water. It is a form of mixing and occurs simply because most materials expand and rise when heated. For example, warmed air rises, which is why smoke from fires drifts skyward. If you stand over a gravity-feed hot-air grate, the warm air currents transfer heat to your feet via convection. This mode of heat transfer can be blocked by physical barriers that inhibit the movement of air and other fluids.

Finally, heat can be transferred through a change of state, also called latent heat. It refers to the amount of heat taken up when a substance melts from a solid to a liquid or evaporates from a liquid to a gas. Changes of state consume vast quantities of energy. For example, it takes 180 British thermal units of heat energy to heat one pound of water from freezing to boiling.* One thousand additional Btus are required to evaporate the same pound of water into steam, without increasing the temperature of the steam at all. The enormous capacity of water for latent heat explains why a filled teapot cooing over a redhot burner doesn't explode. The energy of the flame is used to convert water into steam. This principle also explains an important aspect of the human body's system for temperature regulation. The body releases excess heat by sweating, and the evaporation of this fluid uses up and draws away from the body large amounts of heat energy. Latent heat is also responsible for the air-conditioning influence of plants. Plants evaporate huge amounts of water, drawing heat from the air in the process and storing it as latent heat in gaseous, water vapor. This process lowers the ambient air temperature and increases humidity. In one sunny, summer day an acre of turf can transfer more than 47,000,000 Btus of energy, enough to evapo-

*The definition of a British thermal unit is the amount of heat energy needed to heat one pound of water one degree Fahrenheit. Therefore, it takes (212-32) or 180 Btus to heat a pound of water from freezing (32°F) to boiling (212°F).

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rate about 6,800 gallons of water. One square meter of grass can return half a ton of water to the atmosphere in the course of a growing season, transferring tremendous amounts of energy. Temperatures over grassy surfaces are about 10 to 14 degrees Fahrenheit cooler than temperatures over exposed soil because grass evaporates water and transfers heat energy of the air into the latent heat of water vapor. Obviously, plants must draw upon vast supplies of water to produce this dramatic cooling effect.

If you have a good understanding of heat, temperature, and heat transfer, the other factors contributing to comfort—humidity and air movement—are easier to understand.

Relative humidity is the ratio of the actual amount of moisture in the air compared to the maximum amount it could hold at a given temperature. As humidity increases it approaches the saturation point, the point at which it can hold no more moisture, and precipitation as snow or rain occurs.

With increasing humidity, it becomes harder to add more water to the air. It is more difficult to evaporate sweat in humid environments because the air is already approaching its saturation point. That is why you feel more uncomfortable in humid environments; it is more difficult to unload excess body heat by sweating and evaporation. When a relative humidity of 60 percent or more accompanies a temperature of more than 80°F., it feels uncomfortable, muggy, and humid. In an arid, desert climate, the same temperature would not be uncomfortable because body heat could be easily transferred into the air by sweating and evaporation. On the other hand, high humidity at low temperatures accentuates the impact of cold because it speeds heat loss and gives an unpleasant, raw feeling. When the air temperature is much lower than body temperature, conduction takes over. The air's specific heat is higher when moist, and it rapidly draws heat away from the body.

Air movements also contribute significantly to comfort and are measured by recording their velocity and direction. They have their greatest impact on comfort by increasing heat transfer. In hot, humid climates air movements are desirable because they increase evaporation and heat loss, but in hot, arid climates winds may be undesirable because they carry away precious water. Air movements in cold weather are undesirable and even dangerous because they carry away heat. The notorious "wind-chill" factor describes the accelerating impact of air movement on heat loss. For example, at zero degrees a casual well-clothed hiker need not worry about frostbite if the air is still. But at 20°, if a gusty 40-mile-per-hour wind is blowing, cautions should be taken to guard against excessive heat loss from the body's extremities, which may lead to frostbite.

However, the ability of humans to adapt their physiology to extremes of climate is limited. Our ability to survive depends on our aptitude for analyzing climates, and then manipulating our environment and building shelters that adapt to the available conditions. The following sections analyze the forces sun and wind —and indicate how our homes and offices can be designed to minimize the impact of adverse weather. We emphasize the value of using the landscape to temper extremes of climate and to promote human comfort.

The Sun

The sun commands the daily genesis of weather and is the greatest single force affecting climate. Its radiant energy drives the machinery of climate all over the world. Annually, the earth makes a 600-million-mile orbit around the sun in an elliptical path and, at the same time, rotates on its own axis from west to east, making the sun appear to move from east to west. Knowledge of these two types of motion enables us to predict the sun's "position" in the earth's celestial dome. This permits some manipulation of the environment to utilize the sun's energy to best advantage. During warmer periods, the goal is to block the sun's radiant energy from entering living areas. But at other times, all available radiation should come into the home.

Acquiring an understanding of the sun's path, the arc it travels in the sky, is the first step to planning energy-efficient design. The solar path has two components: its absolute height in the sky, measured by the altitude angle; and the distance it travels on its path between the eastern sunrise and the western sunset, called the bearing angle. All positions in the solar hemisphere can be described by these two measurements. The bearing angle is defined in reference to due north because most people learn to read maps from this perspective. (However, in some disciplines, including architecture and some branches of engineering, it is customary to measure bearing angles from due south.)

You will notice that the seasonal changes in the sun's arc are most striking as you travel away from the equator. As you travel north, the period of daylength increases dramatically in the summer, until you reach the extreme of midnight sun in the arctic. In northern regions in the summertime, the sun rises farther to the northeast and sets farther to the northwest. In the winter the sun's shorter path originates farther southeast and sets farther southwest and barely rises over the horizon.

But in the extreme north, no matter the length of the sun's arc, it never climbs very high into the sky. One must travel south, toward the equator and into the tropics, to witness the sun directly overhead.

The ability of the sun to add radiant heat to a building depends both on its position in the sky and on the intensity of sunlight. The intensity of radiant energy reaching the earth depends on a number of variables, including the presence of clouds, smog, and, most importantly, the density and thickness of the atmosphere. During winter the sun is lower in the sky than it is during the summer, and radiant heat must pass through a larger slice of the atmosphere to reach the earth than it does during summer. The longer trip through the atmosphere diminishes the sun's intensity. That is why the winter sun is generally weaker than the summer sun. However, if we use proper building design the winter sun can still contribute valuable radiant energy, despite its diminished intensity.

As light and heat in the form of solar radiation penetrate the atmosphere to the earth, a variety of things may occur. A fraction is reflected back into space from high clouds; part is scattered into the sky vault as it strikes small particles in the atmosphere; and part is absorbed and reradiated by the gases in the atmosphere. The remaining radiation penetrates to the earth's surface where it is either absorbed or reflected by the ground, buildings, plants, and animals. Absorbed radiation heats the objects, which can then reradiate the heat. Reflected radiation is not absorbed and is bounced back into the immediate atmosphere. In nature, most surfaces absorb some radiation and reflect another portion.

Control of Radiation by Plants

Control of both absorbed and reflected radiation is necessary to maintain human comfort, and this can be achieved by complete obstruction or filtration of direct radiation, or by the reduction of reflected radiation. Trees, shrubs, grasses, and other ground covers are among the best materials for the control of solar radiation.

They offer climate control in tropical regions, where solar radiation is almost always oppressive, and in temperate regions, where solar radiation requires only seasonal control. Plants interact with solar radiation to influence microclimates in two ways. First, plants absorb solar radiation and cast shade. Second, most of this captured, radiant energy is used to transpire and evaporate water from plants. This converts most of the captured sunlight into latent heat, and relative humidity is increased instead of air temperature. The remaining captured radiation is used in photosynthesis. In particularly dry air, plants may actually lower ambient air temperature if they have sufficient water to transpire.

Selected plants can almost completely block the sun's rays. Species such as Norway maple *(Acer platanoides)*, red ash *(Fraxinus pennsylvanica)* and the small-leafed European linden *(Tilia cordata)*, which have dense foliage, multiple leaf layers, or a dense canopy, can absorb and block at least 95 percent of the sun's energy in the visual spectrum and 75 percent across all radiation spectrum combined. A more modest filtration of solar energy occurs when plants with open, loose foliage, including vines and trees such as honey locust *(Gleditsia triacanthos)* and pin oak *(Quercus palustris)* are used. One advantage of vines is that they offer shade almost immediately after planting while trees take longer to mature.

In temperate climates deciduous plants in full leaf are generally the best interceptors of direct solar radiation. They offer their strongest sun-blocking potential in summer, and in winter, when their leaves have been shed, they permit desirable sunshine to penetrate. The dynamics of seasonal foliage variation provide natural sun control. When evaluating plants as sun filters the species' shape must be considered along with its density. Each plant casts a distinctive shadow, which may be round, oval, pyramidal, or columnar in form. Consider the form of the area to be protected before selecting plants to cast shade.

Reflected radiation from the sun is best controlled by plants with coarse surfaces. The multi-faceted surfaces of leaves are much better at reducing reflection than the light, smooth surfaces of man-made pavements or architectural materials. Dark plants with smaller leaf surfaces such as conifers (*Pinus* species, for example), or plants with pubescent, fuzzy surfaces, such as elm (*Ulmus* species), greatly reduce reflection. Vines growing up walls or trellises and ground covers such as grass, pachysandra, or ice plant *(Mesembryanthemum)* also buffer against unwanted reflection.

By blocking or filtering direct or reflected sunlight, plants can temper local climates in a powerful fashion. In the daytime, the ground temperature in a forest may be as much as 25°F. cooler than the top of the tree canopy. At night the foliage mass prevents reradiation into the sky, and the temperature at the forest floor will be warmer than the temperature at the canopy. At midday, a vine-covered wall is always cooler than a bare wall. Dramatic proof of how plants relieve the sun's impact by casting shade was gathered by researchers in California's Imperial Valley, who found that bare-surface ground temperatures ranging from 136° to 152°F. cooled an average of 36°F. in only five minutes after the arrival of the shadow line from overhead foliage.

Wind

The sun provides the energy that drives atmospheric motion or winds. They start blowing when warm air, expanding, rises and cooled air, contracting, sinks. From this simple beginning the behavior of winds grows almost inconceivably complex. Air movements, if at low velocity, are usually pleasant and desirable. However, when the velocity increases, they are capable of causing great discomfort and destruction to life and property.

Winds are grouped into three categories: local and regional persistent winds; global persistent winds such as the trade winds of the tropics; and maverick winds such as cyclones, tornadoes, and hurricanes. Local persistent winds are almost invariably small-scale convection winds—the sea breeze, the land breeze, the mountain wind, and the valley wind. They are of great importance in influencing human comfort, and they can be controlled with careful landscape design.

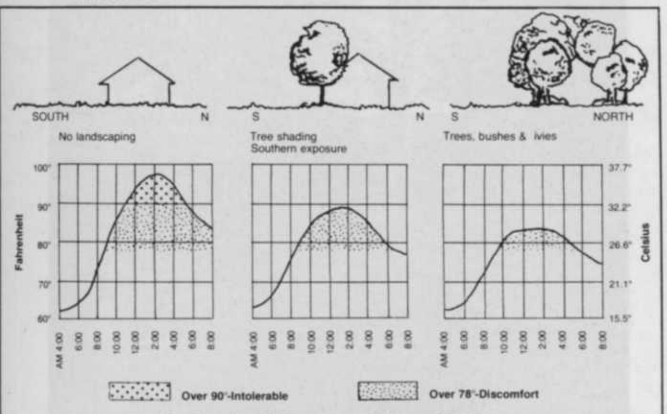
Air flows in much the same way as water. Cold air settles to the lowest level and hot air rises. It will flow over, under, and around anything that is sturdily engineered, and will be bent, bounced, and resisted by obstructions such as buildings, fences, hills, valleys and other earth forms, and plants. Air movements, again like water, exert pressure against any surface that inhibits their flow. Whenever the wind flows over a solid barrier there is increased pressure upwind (where the wind blows from) and a protected, low pressure area immediately downwind or leeward (where the wind blows to). However, the low pressure area pulls the boundary layer of air flowing over the barrier into it. Thus, the lee side of a slope receives protection and contains a pocket of relatively still, quiet air. But this protected region has a limited range because the low pressure region sucks wind back into place.

In contrast, a pierced barrier allows some wind to penetrate through it and creates less pressure differential between the upwind and the downwind. This penetrable windbreak has less wind reduction near it, but the overall calming effect extends farther beyond it. The suction immediately behind this penetrable windbreak is less than that produced by a solid barrier, and the acceleration of wind back to its original speed is more gradual.

A windbreak of trees acts as such a penetrable barrier. These windbreaks are most effective when placed perpendicular to the prevailing wind.

Wind Control by Plants

As we have seen, heat loss from a building's surface is proportional to the square of the wind velocity (that is, the speed of wind multiplied by itself). Wind increases heat loss by convection and by adding to the volume of cool air blown into a building, which subsequently may need to be heated. Therefore, a carefully situated windbreak of trees and shrubs can be a powerful energy saver in climates with periods of cool weather.



Landscaping effects on summer temperatures of a house in a temperate climate

Because the quality of wind protection depends on the penetrability, height, and width of the plants used, recommendations for certain species as windbreaks are difficult to make. The more penetrable the windbreak, the more modest wind reflection to leeward, but the farther behind the windbreak this modest protection extends. Dense, coniferous evergreens that branch to the ground provide the most effective year-round plants for wind control, and deciduous trees and shrubs in full leaf are effective in summer.

In general, wind speed is reduced for a distance of two to five times the height of the barrier upwind of an obstruction, and up to fifteen times the height downwind. The maximum shelter from wind is obtained from three to five times the height of the barrier (downwind). Wind velocity is cut up to 80 percent directly downwind of a dense screen planting such as spruce (*Picea* species) trees. For example, a windbreak of two-foot Austrian pine (*Pinus nigra Laricio*) cuts a 12-mile-per-hour wind velocity to 3 miles per hour. A loose barrier of Lombardy poplar trees (*Populus nigra* cv. 'Italica') in full foliage reduces leeward wind velocity by only 40 percent. In general, a leafless deciduous tree has only 60 percent of the wind-blocking ability of its full, "leafed" potential. Irregular windbreaks that have some foliage density throughout their height are most effective at breaking up the airstream over it. Therefore, a mixture of species and sizes of plants makes a better wind control.

The lower wind velocities on both sides of windbreaks encourage precipitation to fall out of the air. This means that small snowdrifts and large snowdrifts may be formed downwind of a windbreak. The rules that explain how plant barriers influence air movements also explain how such barriers affect snowdrifts. The downwind drifts near a solid barrier are deep and do not extent a great distance from the barrier. In contrast, the downwind drifts near a penetrable windbreak are shallow, extending to a greater distance from the barrier. Solid barriers produce drifts on both sides, and more open plantings keep the drift to the downwind side. The greater the velocity of the wind, the closer the drift to the barrier itself. A well-designed windbreak will slow the velocity of the wind and cause snow to be deposited before it reaches a path or driveway. In snowy climates, windbreaks should not be put immediately upwind of driveways or walkways, but rather a considerable distance upwind.

Plants that provide protection from wind to leeward may also produce a pocket of cold beneath them. Plant designs that group trees for wind control and permit the accumulation of snow and undisturbed litter beneath them insulate the ground. This means the ground warms slowly on a sunny day. This ensures that snow thaws later and more evenly in the spring. Spring perennials, including forsythia and early flowering bulbs, planted beneath such windbreaks will be well insulated against wind and subzero temperatures, but will bloom later in the spring.

It is also important to recognize that at a break in a wind barrier high pressure is released and the wind velocity increases above its open field velocity. This is known as the Venturi effect. For example, just past the edge of a moderately dense shelterbelt, wind speed is increased 10 percent above open field velocity. Also, because the foliage mass of a tree serves as a direct block to the passage of air, air movements directly beneath the leaf canopy may be accelerated. Therefore, careful placement of a windbreak is essential, and poorly placed windbreaks should be removed. Their growth should be carefully monitored to prevent the development of scrawny bare spots near the ground that encourage the acceleration of wind. If trees with high canopies are desired for a windbreak, fill in the bare spots beneath them with shrubs and bushes.

The Venturi effect may also be used to blow areas clear of snow and to provide snow-free parking areas, walkways, or roadways. Alternatively, plantings may be designed to channel winds and cause desirable snowdrifts and deposits on ski trails and toboggan runs.

Plants that block wind may also prevent heat loss by adding a layer of insulating air around a building. A hedge of yew (*Taxus* species) or privet (*Ligustrum vulgare*) adjacent to a wall will provide a pocket of dead-air space, insulating against heat loss.

In addition to obstructing, filtering, and deflecting winds, plant barriers may channel and accelerate beneficial breezes into defined areas. This strategy is desirable in warm climates when cooling breezes are needed. A funnel of trees or tall hedges that guides the prevailing winds can provide constant, natural "air

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conditioning." Because of the Venturi effect, as the funnel narrows, wind velocity increases, making the arrangement more effective. A large scoop that contracts in breadth can increase the velocity of prevailing winds that are light but steady and would otherwise be ineffectual. If the narrowest end of the funnel is covered by a breezeway or a tree with a high canopy, the effect improves. Also, since cooler winds flow downhill, dense evergreens planted on a slope may trap and hold cold air, creating cool spaces, upwind of the barrier.

Effective wind controls demand careful analysis of the direction and strength of the prevailing winds at different seasons.

To learn the direction of all air movements, tie strips of cloth on several posts, five or six feet tall. Anchor them securely at all compass points, plus any suspected odd wind pockets. Study the wind movements for at least several weeks each season and chart them. This information will guide landscaping plans. In more northern areas, wind patterns around buildings may also be traced by watching the way snow is deposited. Make your first observation after a fresh snow on a calm day. Later observe the shift in snow patterns when the wind has blown channels and paths. Note where the ground is bare, and where the snow has piled in drifts. A third method for determining wind patterns is to study smoke released from a chimney, campfire, or barbecue.

Before planting trees or shrubs to control wind, check whether your selected species can withstand the region's strongest storm forces. Trees may fall onto buildings, causing injury or damage. Keep all trees pruned. Deadwood and weak or unbalanced branches are vulnerable to strong winds. It is prudent to plant soft-wooded trees a safe distance from outdoor living areas and buildings if possible. Generally, the fast-growing trees such as pine (*Pinus* species) and larch (*Larix* species) have soft woods and are weaker. Silver maples (*Acer saccharinum*), poplars (*Populus* species), willows (*Salix* species), and black cottonwoods (*Populus trichocarpa*) are especially susceptible to breakage. **WTT**