JOURNAL OF
ARBORICULTURE

November 1977
Vol. 3, No. 11

TREES MODIFY METROPOLITAN CLIMATE AND NOISE[1]

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Abstract. Human comfort in urban areas is altered by trees primarily through their influence on the exchange of radiant energy — both solar and long-wave. Although urban trees probably use large amounts of heat for transpiration, this process does not result in significantly cooler air in the vicinity of single or small groups of trees. Even low winds quickly disperse the cooled air. Outdoor spaces that receive heavy pedestrian use should be made as versatile as possible by providing both sunny and shady sites for sitting and walking. Windbreaks may reduce energy requirements for heating buildings by 10 to 25 percent. Although shade obviously is a benefit in summer; winter shade is a disadvantage, and even deciduous-tree shade is significant in winter. Trees are useful for noise control primarily because they scatter sound waves, which are then absorbed by the ground. Dense forests or plantings of trees can reduce transmission of traffic noise, but if highways carrying high-speed truck traffic pass through residential areas, tree barriers alone cannot reduce sound levels to an acceptable maximum within about 350 feet of the highway.

Modification of climate by trees is important to people in many ways. For example, the alteration of climate by trees may indirectly affect dispersion of pollutants and distribution of rainfall. However, I will concentrate on the human-comfort and energy-conservation effects of trees in metropolitan areas.

A brief survey of current knowledge about the use of trees for noise abatement is included here because trees used for noise abatement also influence climate. Reports by different investigators conflict rather strongly. Some attribute almost magical powers to trees as noise attenuators; others contend that trees are worthless for this purpose.

TREES AND CLIMATE

Scales of climate

Climate is normally studied and described at three scales: (1) the macroscale, with horizontal dimensions of hundreds of miles; (2) the mesoscale, with dimensions of metropolitan areas; and (3) the microscale, with dimensions of a few hundred feet or less horizontally and tens of feet vertically. Hence, the microscale corresponds in size to city streets and small parks.

At the macroscale, the effects of trees and vegetation on climate are difficult to estimate, and considerable controversy exists about these effects. I will not discuss macroscale effects of vegetation on climate, but rather will concentrate on the meso- and microscale effects. At smaller scales the thermal comfort of people outdoors and the energy use for heating and cooling buildings is more directly affected by trees. Hence the effects of trees on climate are most apparent at the microscale.

Human thermal comfort

Increasing use is being made of mathematical equations to describe numerically how comfortable an average person would be in a particular location (Morgan and Baskett 1974). Measurements of atmospheric conditions and the characteristics of the surrounding space provide values that are entered in the comfort equations.

One set of such studies was conducted recently in Syracuse, N.Y. (Herrington and Vittum 1975, Plumley 1975) and on the University of Connecticut campus (Stark and Miller 1975). The main emphasis was on determining the importance of different kinds of energy exchange and weather variables in designing outdoor

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[1] Presented at the annual meeting of the International Society of Arboriculture in St. Louis, Missouri in August 1976.

spaces for human comfort.

Air temperature is obviously an important variable in determining human comfort. However, at about the 5-foot height, no significant difference in air temperature was found between sites with small groups of trees and sites without trees in the downtown business district of Syracuse (Herrington and Vittum 1975, Plumley 1975). Trees individually on in small groups do not change air temperature in their vicinity by enough to affect people.

It was also found that the humidity of air does not vary much over short distances in a city. Groups of trees and even a large fountain did not change humidity enough to affect human thermal comfort (Vittum 1974). These findings about temperature and humidity in Syracuse are probably representative of most U.S. cities. Therefore, in designing relatively small outdoor urban spaces there is little need to consider the effects of trees and other vegetation on air temperature or humidity.

Air movement accounts for the fact that neither air temperature nor humidity is significantly affected by a few trees. Transpiration may cool air adjacent to trees rapidly. Federer (1976) calculated that urban trees well supplied with water may transpire at a rate sufficient to provide cooling equal to the effect of five room air-conditioners. However, the Syracuse studies indicated that the cool, moist air would be removed quickly from the vicinity of the tree and dispersed by even a gentle breeze.

These observations might seem to refute the concept of trees as "Nature's Air Conditioners." But I am talking now about only the microscale. At the mesoscale, the cumulative effect of trees on air temperature is significant. In an article of 20 years ago in AMERICAN FORESTS, titled "Nature's Air Conditioner," Landsberg (1956) described a typical temperature regime for a summer day in downtown Washington, D.C., as contrasted with the temperature regime of Washington's Rock Creek Park, which is nearly 3 square miles of land covered with grass and trees, with elevation differences of 150 feet and with moisture readily available for evaporation. The city had temperatures above 90 degrees F for 5½ hours. In the park it was above 90 degrees F for only 3 hours.

This concept of the entire Rock Creek Park — including trees, topography, and a plentiful water supply — as "Nature's Air Conditioner" is in sharp contrast to some literature (Haller 1969, Rich 1973) that implies that in cities a few scattered trees or even single trees can act to change air temperature beneath them by 10 degrees F or more.

Although air temperature and relative humidity cannot be significantly altered by a few trees, wind and radiation environments most definitely can be. For cold-weather conditions, wind is the most important variable for human thermal comfort and safety, because wind increases convective heat loss (i.e., removes warm air molecules). Designers could make greater use of trees for wind reduction in many urban situations. However, for sites to be used during both warm and cold weather, trees should not form an extremely tight enclosure as a thicket that would essentially reduce wind speeds to zero. This is because, for warm conditions, lack of air movement adds to discomfort in people by reducing both convective and evaporative heat losses (Waggoner 1963, Herrington *et al.*, 1972). Light breezes are desirable during warm conditions, but winds higher than breezes do not increase comfort significantly.

A fact that was emphasized by the Syracuse and Connecticut studies is that long-wave radiation exchange between people and outdoor surroundings can be controlled by trees. Considerable heat is stored in city structures exposed to solar radiation, and the stored heat keeps the surfaces of these structures warm all night. Trees can be used to control the heating of the surfaces by screening them from solar radiation and to provide a screen between hot surfaces and people.

The most important variable affecting human thermal comfort is usually solar radiation, and fortunately trees can be used effectively to control this variable. Trees with dense canopies can reduce by 80% the solar radiation a person receives (Plumley 1975). Shade-tolerant species such as maples have denser canopies and provide more shade than shade-intolerant species such as honeylocusts.

For campus situations, the amount of vegetated surface within view of a person has been related to heat exchange by radiation (Stark and Miller 1975). The most comfortable warm-season conditions existed when between 45 and 73% of a person's view was of vegetation.

Trees and human behavior in urban design

Recent studies (Robertson and Rowntree 1975) have shown how thermal comfort is not always uppermost in the minds of park users. For example, an advantageous view of members of the opposite sex may far outweigh physical comfort when people choose places to sit. Many park and plaza users seek sunny spots on hot days to acquire a tan. Further, in slightly cool locations or on cool days, people may seek sunlight for comfort. The important point is that designers should make urban parks as versatile as possible by providing a range of comfort conditions with both sunny and shady sites (Plumley 1975).

Trees for modifying energy consumption of buildings

In popular literature there is frequent mention of the effect that trees have in reducing use of fuel for heating homes. Little quantitative information is available. We usually read statements indicating only that it is good to have trees around houses because fuel bills are lower. Sometimes the generalization that trees lower fuel bills "as much as 40 percent" is included. This is a rather optimistic estimate, evidently taken from a report by Bates (1945), who predicted that fuel savings of as much as 40% were possible in the northern shelterbelt states, with "all-round protection in the center of a grove or forest."

Trees as windbreaks

Wind can alter building-energy budgets to a considerable extent. Formal studies of the windbreak effect of trees on fuel consumption for heating buildings were first carried out at least 60 years ago (Bates 1911). The general conclusion of these and later studies was usually that trees for windbreaks have the potential to reduce winter fuel consumption by 10 to 25%. The 40% reduction potential suggested by Bates (1945) was not derived from experimental results.

Wind influences the energy budget of buildings by convecting heat away from or to the exterior walls and by causing infiltration of outside air. For townhouses in a planned unit development in New Jersey, it was estimated that on the average one-third of the heat loss in winter through exterior walls was by conduction (Fox 1973). Part of this conducted heat would then be transferred to outside air by convection. Infiltration of outside air accounted for roughly another one-third of the heat loss. One-third was lost through window glass.

Air infiltrates buildings through cracks around windows and doors, and also through pores in the material of walls (Georgii 1953, Geiger 1965). Generally wind speed strongly influences infiltration (Georgii 1953, Mattingly and Peters 1975). Except at low wind speeds, infiltration depends only slightly on the difference in temperature between the inside and outside of buildings.

Studies of the effect of Great Plains shelterbelts on house heating pertain to relatively wide belts of deciduous trees. For a study in South Dakota, two simulated test "houses" that were about 4 feet on each side were used (Bates 1945). Shelterbelts were simulated by fences of vertical wooden slats. Wind information from actual shelterbelts was used, and a 25% saving of fuel was calculated for a house sheltered on the north side by a 10-row deciduous windbreak. For small yards in towns, a compact mass of evergreens close to the house was recommended, but no calculations of fuel saving were given.

From a 1954 wind-tunnel study at the Kansas Agricultural Experiment Station, it was calculated that a 10-row defoliated shelterbelt would provide a 15% saving in heating costs for a house located two tree heights south of the belt. An average wind of 10 mph was assumed; other climatic conditions were those of Topeka, Kansas (Woodruff 1954).

A recent wind-tunnel study at Princeton University tends to show that windbreaks are also effective for the Northeast. This was a study of the effect of trees on air-infiltration rates for town houses in a planned unit development in New Jersey (Mattingly and Peters 1975). A single row of trees was modeled by mounting triangular wire screens on vertical metal shafts. Visual density of the model windbreak approximated that of a single row of white pine (*Pinus strobus*) or Norway spruce (*Picea abies*) trees. Tree models were equal in height to house height. Potential reduction of air infiltration was as much as 40%. It was calculated that the reduction in infiltration by a single row of tall conifers could mean a 13% reduction in fuel use at certain times. When the model included a 5-foot-high fence between the trees and the house, infiltration was reduced by 60%. A dense hedge would probably serve as well or even better than the fence.

The Princeton wind-tunnel study added to our knowledge of how windbreaks function. The windbreak reduced air infiltration by effecting a more even distribution of air pressure around the entire house, rather than by simply reducing the speed and hence the force of the wind on the windward side. This suggests that windbreaks may be most effective when placed quite close to buildings, even though maximum windspeed reduction near ground level takes place about five tree heights downwind of tree barriers. A new research project at Princeton is exploring windbreak placement.

Recent research at Pennsylvania State University (Jacobs and DeWalle 1976) explored the effect of both shade and wind reduction on space heating for a camper-trailer in winter. Infiltration of cold air into the trailer was as much as 50% less in a pine plantation than in an open site. Due to reduced air infiltration, the energy required for heating the trailer in the pine forest was generally reduced. However, on sunny days the forest canopy reduced the natural heating of the trailer by solar radiation. Still, for an entire heating season, it was estimated that 5% less energy would be required for heating the trailer in the pine forest. Research at Penn State is continuing with a year-round study of air infiltration rates and energy requirements for space heating and cooling of dwellings in deciduous and coniferous forest settings.

Flemer (1974) compared fuel consumption in a New Jersey house before and after an evergreen windbreak was installed. When the trees reached the height of the house, a fuel saving of 10% per winter over the former exposed condition was recorded.

Trees for summer shade

Tree shade decidedly affects external surface temperatures of buildings. Using an infrared radiation thermometer, I have noted temperature differences of 9 degrees C (16 degrees F) between unshaded and shaded white surfaces of wooden houses in New Jersey in June. The shade was from a large sugar maple (*Acer saccharum*). Greater temperature differences occur with dark-colored surfaces.

Unfortunately, there is not much quantitative information about the effect of tree shade on air temperature inside buildings. In a study in California, Deering (1956) showed that dense shade from trees might reduce maximum temperatures in houses by 20 degrees F (11.1 degrees C). A 20- by 8-foot house trailer simulated a typical low-cost frame house. Construction included 2- by 3-inch studs, white clapboard siding, and an asphalt-shingled roof. When the trailer was beneath a group of large fig trees that provided shade all day, the temperature inside the trailer remained above 75 degrees F (23.9 degrees C) only 5 hours in comparison to 11½ hours above 75 degrees F in full sun. Maximum temperature inside the trailer was 84 degrees F (28.9 degrees C) when it was in the shade, and 104 degrees F (40 degrees C) when it was in full sun.

A study in Alabama (Laechelt and Williams, n.d.) showed that mobile homes located in tree shade had power bills $45 to $100 (in 1973) per year less than mobile homes without shade. The shade did not have to be complete for good results. If a "roof averaged 20 percent or more shade for the entire day, lower air conditioning costs were prevalent."

It is convenient that deciduous trees, which are generally best for shading, lose their leaves in winter and allow passage of much solar radiation to provide heat in winter. However, more solar radiation is absorbed by leafless deciduous trees than is usually realized. Measurements in forests have shown that, at low sun angles, as much as 80% of incoming solar radiation may be absorbed by leafless trees (Federer 1971). Even at high sun angles, 40 to 50% of solar radiation is absorbed by forests. A house surrounded by deciduous trees is significantly shaded even when the trees are leafless (Figures 1 and 2).

Figure 1. A house well-shaded by deciduous trees that were left standing when the house was built in a woodlot, midday in June.

Figure 2. The house shown in Figure 1 as it appeared at midday in March. Note that bare trees still shade substantial portions of the house.

TREES AND NOISE

One obvious way that trees are useful for noise control is in reducing human perception of noise by creating a masking effect through the rustling of leaves or needles by wind. The sounds of birds and other animals also create masking in well-treed areas. In late summer, katydids and crickets in forests are effective in overriding unwanted sounds . Noise-masking is a useful technique for treating the problem of noise that is simply annoying rather than overwhelmingly loud.

For loud noise, such as that from a major highway within a few hundred feet, trees are useful in actually attenuating sound. However, wide tree barriers are required to reduce these noises to a sound level that is normally acceptable in a community. This level is 60 dBA or about one-eighth of the apparent sound of a loud diesel truck traveling on an interstate highway 50 feet away.

In a field test in Nebraska (Cook and Van Haverbeke 1971), diesel truck noise was reduced to the acceptable level at 350 feet from a highway with a strip of trees 100 feet wide and 45 feet tall between the highway and the receiver. Without the trees, and the sound passing over a field, the noise would have been above the acceptable level out to 450 feet from the highway.

It has often been suggested that people are less conscious of noise if they can't see the source. Trees, then, might be very useful by providing an esthetically pleasing visual barrier between houses and nearby noise sources, such as a highway. However, the effectiveness of trees as psychological tools for this purpose has been tested only once under controlled conditions (Aylor 1975). This test showed that *partially* screening a noise source did make experimental subjects think they were hearing less noise than they actually were. However, *fully* screening the noise source seemed to cause the opposite effect — the subjects thought the noise was louder than it actually was. A possible explanation for this result is that people expect a visually solid barrier .to be quite effective in reducing noise. When, as in the experimental situation, the noise is not reduced, it actually seems louder.

This experiment on the psychological effects of noise-source visibility should cause us to use caution when recommending a tree barrier for noise control. Happily, in real situations, it seems that most people receive a psychological lift from a barrier of trees between them and a noise source — even if they know the noise is not substantially reduced.

Trees themselves apparently do not absorb much sound. Most investigators now agree that trees are effective in reducing noise transmission primarily by reflecting and scattering sound waves (Aylor 1975; Reethof *et al.* 1975). Tree bark absorbs only a small amount of sound — usually less than 10 percent (Reethof *et al.* 1976). Foliage is also effective primarily by scattering sound rather than by absorption (Aylor 1972a, 1972b, 1975). The most effecitve sound absorber is the ground beneath trees (Reethof *et al.* 1975). Herrington and Brock (1975) studied the variation of sound reduction in relation to height in a forest and found that by far the greatest reduction was near ground level, apparently because of the strong absorption of sound by the forest floor following scattering by foliage, branches, and boles. Hence, it is the combination of all forest elements that makes forests effective in sound absorption.

Some investigators have found that broad-leaved trees are more effective noise attenuators than narrow-leaved species (Aylor 1972a). This is apparently because the length of most sound waves is long relative to the width of leaves and especially long relative to needles. The wider the leaf, the greater the scattering by leaves.

Discrepancies among studies about the value of trees for noise abatement occur partly because of the many different ways in which studies have been conducted. For example, different noise sources have been used — actual highways, lawnmowers, recorded noises, and generators of single-frequency tones or random-frequency noise. Attenuation of sound by vegetation is quite different for different sound frequencies, and these different types of experimental sound sources with different frequency distributions have led to variable results. Further, some studies are full-scale field studies and others are modeling studies performed in laboratories. The modeling studies show great promise for the future, but at present the techniques for laboratory modeling of noise reduction by forests are still being developed.

The discrepancies among study results are compounded by the fact that no satisfactory techniques have been developed for describing noise-attenuation characteristics of forests. The normal measurements of forest trees by diameter, height, number of trees per unit area of ground, etc. seem not to be strongly correlated with amount of noise attenuation.

Though there are differences in opinion about the effects of trees for noise control, I believe most scientists who have studied the use of trees for noise abatement would agree on the following general guidelines:

1. Widely-spaced trees along city streets do not absorb noise and provide a general quieting effect in a neighborhood.
2. Noise buffers should be close to the source rather than halfway between the source and receiver.
3. If major highways carrying high-speed truck traffic pass through residential areas, tree barriers cannot reduce sound levels to a reasonable maximum within 350 feet of the highway.
4. However, if a traffic noise problem exists and only a narrow strip of land is available for plantings, a dense planting of shrubs backed by several rows of trees will be of some help. In such a case, a solid concrete wall barrier would be of definite benefit and would be made esthetically acceptable with trees to hide it.
5. Where the right-of-way is sufficiently wide, such as at roadside rests along major highways, a land-form covered with a dense planting of trees will serve as a worthwhile noise attenuator.
6. If trees are already in place between a noise source and residents who would be bothered by an increase in noise, a hard surface such as a parking lot should not be substituted for the trees.

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ABSTRACT

Anonymous. 1977. **Detecting/controlling tree diseases and pests: maple.** Grounds Maintenance 12(1): 47, 50, 53, 62, 65, 75.

If your maple tree is experiencing an insect or disease problem, this GM guide will help you in determining and controlling the precise cause. More than 100 different species of maple (*Acer*) grow in the world, with a dozen being native to the United States. Usually the maple is not troubled by serious disease or insect pest problems and is, in fact, one of the most easily grown trees. Those insects, pests, and diseases which do occasionally affect maple trees are discussed in the following article. Tables 1 and 2 indicate spray programs which may be used in serious cases.