

JOURNAL OF ARBORICULTURE

May 1986
Vol. 12, No. 5

ENERGY SAVINGS WITH TREES¹

by Gordon M. Heisler

Abstract. In conventional buildings, trees increase, decrease, or have little effect on energy use depending on general climate, building type, tree species, and tree location. Tree arrangements that save energy provide shade primarily for east and west walls and roofs and wind protection from the direction of prevailing winter winds. Particularly for buildings specially designed to use solar energy and those with solar collectors, it is important to place tree crowns so they do not block sun from collectors and south walls. But conventional houses also benefit from winter sun. Deciduous trees provide better year-round shade than conifers, but do reduce solar energy significantly even without leaves. In winter, reductions in solar energy on south walls by a deciduous tree may be greater than reductions by the same tree in summer. Hence, growth rate and crown shape are important criteria in selecting shade trees, and the placement of trees around the house is important. A summary of research data suggests that the maximum potential annual effect of trees on energy use in conventional houses is about 20 to 25% compared to the same house in the open.

Both increased energy costs and our growing awareness that trees modify our environment have created interest in potential energy savings with trees. Trees may increase, decrease, or have little effect on energy use depending on species and location, climate, building design, and other factors (10, 13, 21, 27, 48, 54). Members of ISA have had an opportunity to become familiar with several aspects of tree influence on energy use for heating and cooling buildings; the Journal has included at least a half dozen relevant articles (14, 21, 44, 48, 54, 56).

Although many extension bulletins and even entire books have been written for the homeowner (16, 37), most homeowners probably have not used this information and know little about managing trees for energy saving. In their daily work, arborists can pass on information about tree effects

on energy use and sometimes make decisions that influence energy use, such as where to plant or remove trees or how to prune them.

Urban planners and managers also have a stake in the effects of trees on energy use because trees interfere with solar access (48). Concerns about solar access will lead to demands for changes in street-tree management in many cities, including the use of trees with low winter density and short mature heights.

At the national level, energy use figures provide a perspective on the potential importance of trees. The greatest impact of trees on energy use is in small buildings, particularly detached single-family houses and mobile homes. In 1982, the nearly 58 million single-family detached dwellings in the United States used more than \$63 billion worth of energy; this does not account for wood that is burned for heat (50). About 53% of the total energy use in houses in the nation is for space heating and 12% is for space cooling. Hence, we spend about \$40 billion per year to heat and cool detached housing units—about 8% of all U.S. energy use. A 1% saving of this energy would amount to \$400 million annually.

Some general recommendations can be made for managing trees to save energy. However, tree effects differ with the many differences among local climates, building structures, and existing vegetation. Needs and desires of homeowners also differ. Therefore, better tree management for energy saving will result from knowing 1) how heat moves in and out of buildings in response to

1. Presented at the annual conference of the International Society of Arboriculture in Milwaukee in August 1985.

local climate, and 2) how trees influence this climate. In this paper, discussions of these two topics precede a summary of the results of tests of tree effects on energy use. Recommendations on how to plan and manage trees for energy savings are offered. Some urgent needs for more research are indicated.

Building Heat Gain and Loss

Local climate affects the rate of heat loss or gain from buildings by 1) air exchange; 2) solar radiation transmission through windows; and 3) heat conduction through walls, floors, ceilings, and windows. Trees influence heat gain or loss by all three mechanisms

Air exchange. Even with closed doors and windows, air moves in and out of houses through cracks around doors and windows, and through small pores in walls. The air movement is caused partly by differences in temperature between inside and outside air and partly by wind pressure. In winter, warm, light air inside a house tends to rise and flow out through any openings in the upper levels of a building, while cold dense air replaces the warm air through lower level openings. In summer, the reverse flow may occur, though usually to a much smaller extent than in winter. Because of the wind effect, houses in exposed locations in windy climates tend to have particularly high rates of air exchange, and this is where tree windbreaks are most effective.

The rate of air exchange in a house is measured in building volumes of air per hour, or "air changes per hour." In homes specially designed to be "tight," air exchange may average only a small fraction of a change per hour. In conventional homes, air exchange typically averages about 0.75 change per hour and causes about one-third of all heat loss in winter. Air exchange increases to several changes per hour on cold days with high winds, and causes half or more of total heat loss.

Heat conduction. Heat conduction through the walls, roof, and windows is largely determined by differences in air temperature between inside and outside air. However, both sun on building surfaces and wind also influence heat conduction. Sun increases outside surface temperatures, which tends to cause heat conduction into the

house. There may be a lag of several hours for a peak surface temperature to pass through a wall, leading to high inside temperatures long after the warmest, sunniest time of day.

The familiar R values relate heat flow by conduction to the temperature difference between the inside and outside of building materials. Heat conduction through walls is usually more important than conduction through the roof. Ceilings (typically R-20) usually have thicker insulation than walls (typically R-12), and extra insulation can be added to ceilings more easily than to walls. The relatively great importance of heat loss by conduction through windows is indicated by their low R values—only about 1.6, even for double-pane windows. In calculations for one house in Madison, Wisconsin, 25% of heat loss was by conduction through doors and windows (24, 45).

The degree to which wind affects heat conduction is of interest because it indicates one potential effect of windbreaks. For insulated walls this effect is small; but for windows, a two-thirds reduction in windspeed (possible by windbreaks) can reduce conduction by about 9% for double-pane windows and by 13% for single-pane windows (1, 2, 24).

Heat also moves to and from building surfaces as thermal, or longwave, radiation from hot driveways and sidewalks. Houses may lose heat to cold skies by the same process. Generally, the effects of thermal radiation are smaller than the solar radiation effect.

Solar radiation through windows. Although solar radiation heats houses by heating wall and roof surfaces to cause inward conduction of heat, the main effect of solar radiation is usually by entering directly through windows. The conduction of the sun's heat through 1 ft² of wall or roof may be only about 2% of the heat that would pass directly through a window (9). Still, a substantial amount of heat from the sun can enter houses through walls and roofs because of their large area.

Solar energy provides significant heat input even to houses that were not designed to make optimum use of it. In the previously mentioned Madison house, which was well insulated but with typical window areas, about one-third of the heat input was from the sun during a heating season

(45).

Another indication of the value of sun for winter heating is a recent report (34) which suggested that on average, ordinary single-family detached houses in Portland, Oregon, use between 21 and 25% less energy now than they would if all were in complete shade. The sun's energy now falling on building surfaces and entering windows is worth \$100 to \$300 per house annually, depending on house size and design. Citywide, this total exceeds \$14 million. This does not include houses specially designed for use of solar energy.

Solar radiation is more important when the sun is low in the sky and strikes windows and walls almost perpendicularly, as for south-facing surfaces in winter, and for east- and west-facing windows in early morning or late afternoon in summer (Table 1). Relatively little heat comes through south windows in summer because the sun is so high during the time it is in the southern sky and its rays make a small oblique angle with south windows. At 32° latitude, on July 21, south windows receive only a little more solar radiation than north windows.

Solar path diagrams (Fig. 1) are one means of visualizing the sun's path through the year and they help explain values of solar radiation in Table 1. The bottom of each diagram represents the horizon (elevation angle = 0°), and the top center is directly overhead (elevation angle = 90°). The solid curved lines represent the position of the sun in the sky by month and hour of the day—for example, it is easily seen that from April through August, the sun rises north of east and sets north

of west, rising high in the sky at noon. From October through February, the solar path begins and ends south of east and west and is lower in the sky.

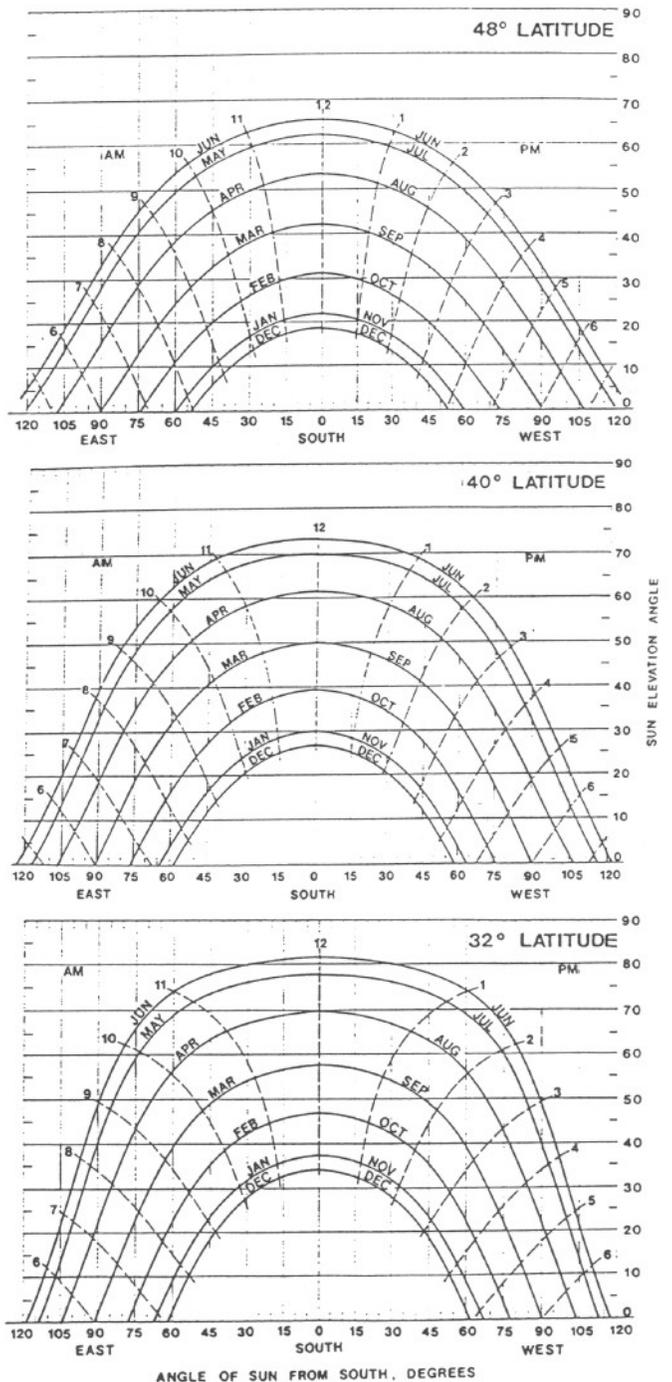


Table 1. Approximate number of Btu through 1 square foot of single-pane window on a clear day for windows facing different directions at three latitudes (January 21 and July 21 are representative of winter and summer).

Direction window faces	32° Latitude (e.g., El Paso, TX)		40° Latitude (e.g., Columbus, OH)		48° Latitude (e.g., Spokane, WA)	
	Jan. 21	July 21	Jan. 21	July 21	Jan. 21	July 21
North	160	460	120	450	90	450
East/west	650	1,150	510	1,190	360	1,230
South	1,710	500	1,630	700	1,400	950

Figure 1. Solar path diagrams for three latitudes that range from southern United States and northern Mexico (32°) to northern United States and southern Canada (48°). The horizontal axis shows true azimuth angles measured from south. Solar paths are plotted on the 21st of each month. (Adapted from Mazria and Winitsky (32)).

Tree Effects on Local Climate

Air temperature and humidity. While trees greatly reduce temperatures of surfaces in their shade, their effect on air temperature and humidity is generally less dramatic (21). Trees do remove much heat from the air by transpiration (14), but the reduction in air temperature is unlikely to be large because much air moves through or around a tree crown. Even though one house in a neighborhood has many more trees, the air temperature around it will not be much cooler than air temperature around other houses. One study (41) has suggested significantly cooler temperatures of walls owing partly to evaporation from adjacent shrubs; but in this case it would seem difficult to separate evaporative cooling effects from indirect effects on air temperature as a result of shading of the wall.

When large trees are well distributed throughout a neighborhood, all of the trees together may have a significant impact on temperature and energy use in buildings, particularly in summer (11, 29, 40). In built-up areas, average temperatures are generally higher in both summer and winter than in rural areas (14). A study in Davis, California, suggested that a mature tree canopy reduced summer air temperatures in a developed area compared to an open field, but immature trees increased air temperatures (33). This was apparently the result of the smaller trees blocking air flow but allowing most of the sun through to heat the ground, which, in turn, heated the air. The tall mature canopy blocked more sun.

Since trees may cause modifications in air temperature in both beneficial and nonbeneficial directions, future research may show a small annual net effect of trees on energy use by changing air temperature.

Longwave radiation. Trees can directly affect thermal radiation heat flows or indirectly affect them by blocking solar radiation and greatly reducing ground surface temperatures. I have not seen data on the thermal radiation effects of trees on building energy use independent of other climatic effects of trees.

Wind. Belts of trees reduce windspeed in a pattern similar to the curves of wind reduction shown in Figure 2. Wind reduction starts several tree heights upwind of the belt and extends to about

30 tree heights downwind, with reductions of 20% as far as 15 tree heights downwind. For most tree rows in leaf or for rows of conifers with no large openings between plants, the maximum reduction is usually between 60 and 85% (24).

The curves in Figure 2 represent maximum reductions which occur when wind is moving over a flat smooth field without obstacles to make the air turbulent. Because most houses are located so that buildings and trees upwind cause the air to be turbulent, windbreaks in typical urban areas would be expected to produce smaller wind reductions than those shown in Figure 2; but to my knowledge nobody has measured reductions by windbreaks in residential neighborhoods.

Partly because of the difficulty of finding neighborhoods of houses that are identical except for the presence or absence of trees, the combined effect of all the trees within residential areas in reducing windspeed is also not well known. Hence, it is difficult to assess the overall effect of trees on energy use in neighborhoods. Measurements with just two anemometers showed a summertime wind reduction of about 67% in a Davis, California neighborhood with many 45-foot deciduous trees compared to a neighborhood with only a few trees with an average height of 15 feet (33). Deciduous trees without leaves are about 50% as effective as with leaves. This suggests wind reductions by the mature deciduous canopy of about 33% in winter.

Solar radiation. The effect of trees in reducing

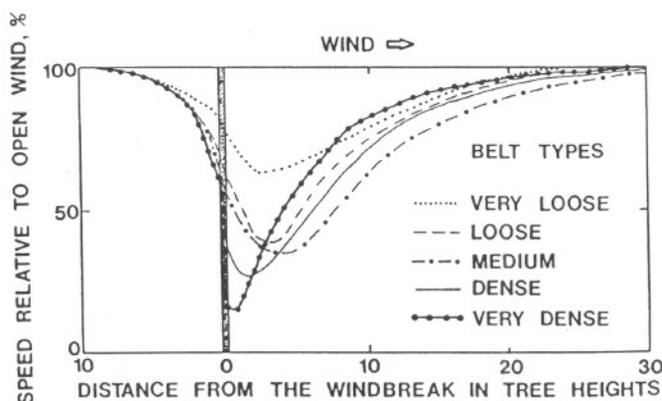


Figure 2. Average relative windspeed (compared to wind in the open) as affected by shelterbelts of different density (38). Distance from the windbreak is measured in units of windbreak height, H .

solar radiation can be measured directly with radiometers or estimated by evaluating tree density by one of several methods. For six individual open-grown trees, we found that radiation reductions were generally proportional to visual density but typically about 5% less than density (25, 26).

Figure 3 shows that density of open-grown tree crowns, in this case without leaves, varies with tree size in different ways depending on species. The curves are based on regressions with data from 20 to 25 trees of each species. These large numbers of sample trees were necessary to obtain valid averages because of substantial variation with size as well as among trees of similar size. These are the only measurements of which I am aware that evaluate the pattern of density change with tree size.

For many tree species commonly used around buildings, density or radiation reductions have been measured in summer and winter; but there is such a large range in reported values from study to study that for many species, average reductions in radiation cannot be predicted with certainty. Differences between studies can result from a number of factors such as small sample sizes, differences in measurement techniques, differences in portion of crown sampled, differences in range of tree sizes sampled, differences in portion of the day over which radiation measurements are made, and measuring with radiometers that measure only part of the wavelength range of solar energy.

The measurements suggest that average reductions in radiation on horizontal surfaces by mature open-grown deciduous trees range from about 70

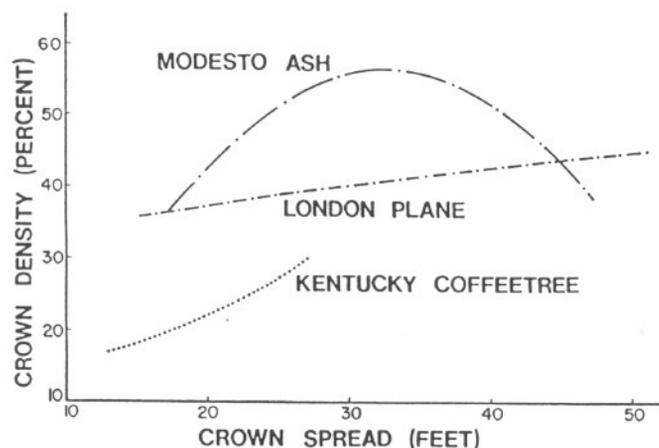


Figure 3. Density of crowns of leafless trees of three species as determined from 35-mm slides (from 51).

to 90% on clear days in summer and from about 20 to 55% in winter (17, 23, 25, 26, 36, 51, 56). There seems to be a consensus that trees with large compound leaves, particularly *Gymnocladus* and *Juglans*, have low winter density, though Figure 3 suggests that winter crown density of large Kentucky coffeetrees (*Gymnocladus dioicus*) could equal density of large London planetrees (*Platanus acerifolia*).

We found that average reductions of solar radiation on walls in the shade of leafless, dense trees such as midsize Norway maple (*Acer platanoides*), sugar maple (*Acer saccharum*), and London planetree (*Platanus acerifolia*), may be 30 to 35% on sunny days, while reductions in the shade of large trees may be 45% (25). Reductions in radiation in winter were about 0.4 to 0.5 of summer reductions (Fig. 4). In winter, with highly reflective snow on the ground, and with the low solar-elevation angles at this time of year, solar energy on south-facing walls can be much greater than in summer. As a result, although the percentage reduction is smaller in winter, the reductions in solar energy by a leafless deciduous tree on clear winter days can be larger than on clear days in summer (25).

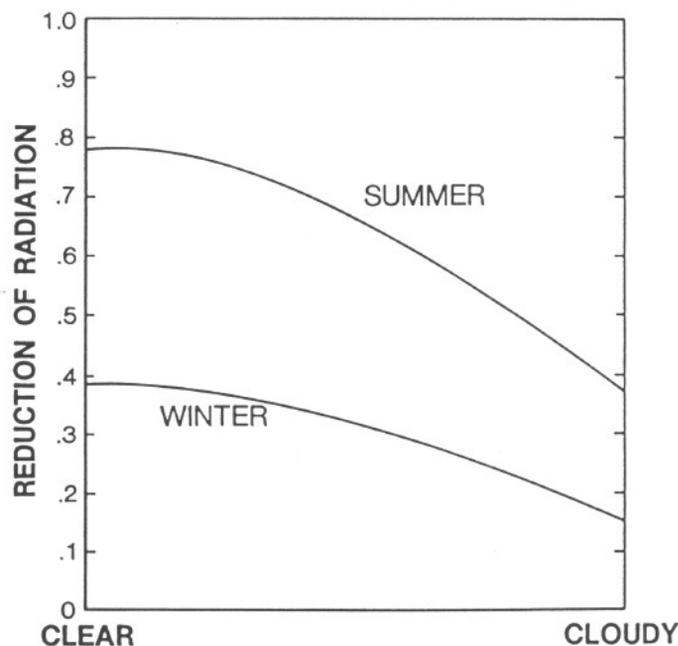


Figure 4. Approximate average fractional reductions in solar radiation on vertical surfaces in the shade of dense, midsize trees such as Norway and sugar maple.

In locations where both cooling in summer and heating in winter are needed, shade trees with low winter density and high summer density would be desirable. In averaging the available data for 21 species for which estimates of winter density have been made in two or more studies, the ratio of winter to summer density ranged from 0.36 to 0.69. Only *Fraxinus pennsylvanica*, *Acer saccharum*, *Liquidambar styraciflua*, *Quercus rubra*, and *Zelkova serrata* had ratios of less than 0.40. *Juglans* and *Gymnocladus*, which are reported to have low winter density, do not seem to have especially low ratios of winter to summer density because summer density is also apparently relatively low. Other species with high winter density such as *Acer saccharum* have low ratios of winter to summer density because summer density is high.

Species such as *Juglans nigra*, *Gymnocladus dioicus*, and *Fraxinus pennsylvanica* also have short in-leaf seasons (18, 36), an advantage for cooler climates. The possibility of tree breeding

for low winter density and advantageous leaf seasons has been suggested (48, 53) since tree cultivars have never been developed specifically for these traits.

Tree position is important in determining radiation reductions on buildings. Trees on the south do not block much sun in midsummer unless they are close to or overhanging the house; yet they do shade large areas in midwinter (Fig. 5). Note in Figure 5 that the south wall is well shaded by 2-foot-wide eaves much of the day in July. For several cities at 40° latitude I computed the solar radiation reductions on the house surfaces by sugar maple trees as depicted in Figure 5 (26). For the unpruned tree on the south, the reductions would total only about 0.7 as much in the months of June through September as in November through April. For the tree on the west, reductions in summer solar radiation were about 4 times those of reductions in winter; the pruned tree on the south had ratios of 1.0 to 1.9 (depending on climate) of summer to winter reduc-

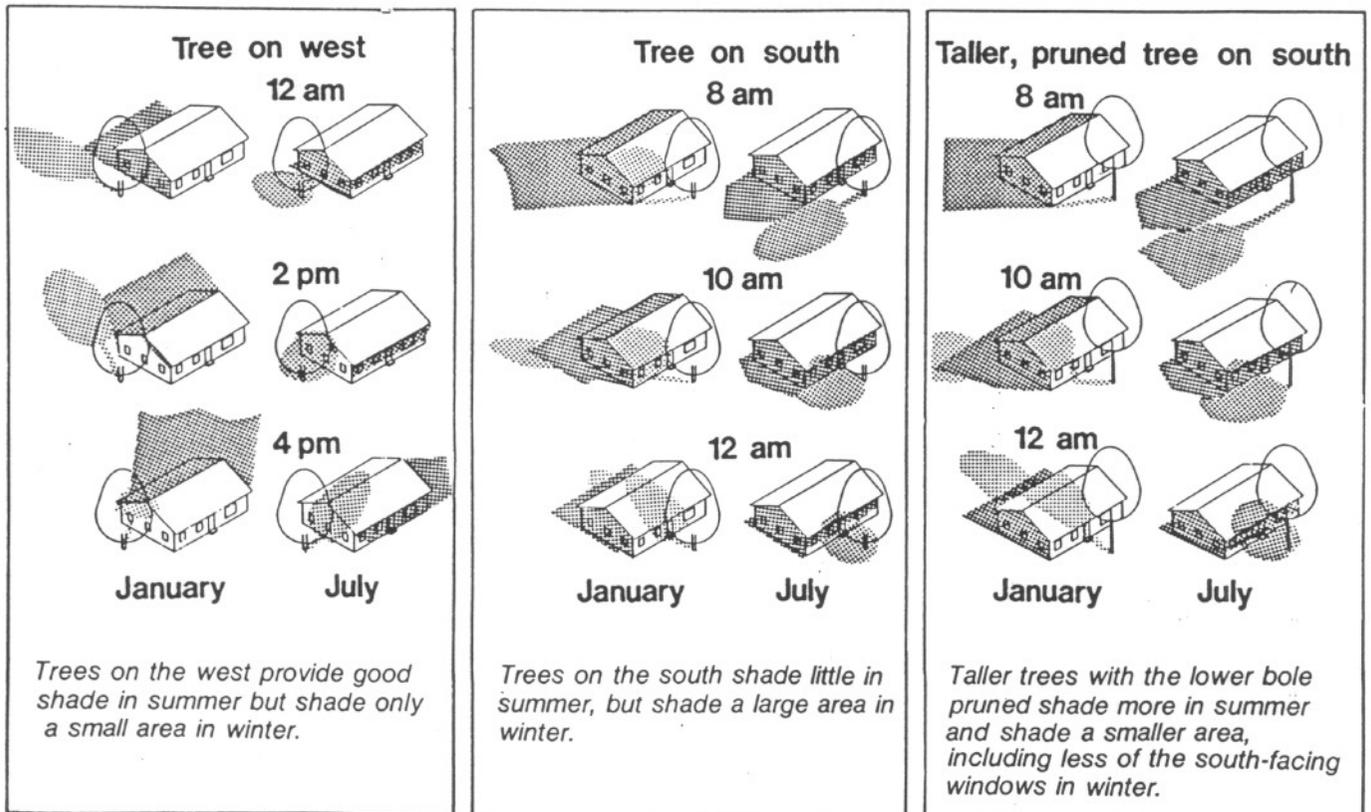


Figure 5. Patterns of tree shade at 40° latitude (about Columbus, Ohio and Denver, Colorado). Even deciduous trees may reduce solar heat input in winter.

tions in radiation.

Measured and Estimated Energy Savings

There has been considerable variation in reported effects of trees on energy use. The variation is partly due to differences in climate, building structure, and tree arrangements, and partly to the method of estimating. A look at where and how some of the studies were done helps give an intuitive feel for potential consequences of particular tree arrangements, though many of the studies are for building structures or tree arrangements that are in some way not typical, leading to probable overestimation or underestimation of typical savings. To my knowledge, no all-year tests of arrangements we generally consider optimum have been made in temperate climates. We can only extrapolate from tests of other arrangements. Also limiting is the fact that comparisons have not been made between energy-saving arrangements and tree arrangements that would increase energy use. The results of such comparisons would indicate the maximum potential for energy saving by tree management.

Windbreaks. Estimated seasonal energy reductions from tree windbreaks range up to 40% (Table 2). The 40% estimate (3) was for an un-insulated 1930's house in the northern Great Plains located in the center of a tree grove. For houses with a windbreak on only one side, estimated savings ranged from 23 to 25%. These estimates, although carefully done, were based on heat loss measurements from 4- by 4-foot test units. The results have been widely quoted in extension bulletins (usually without mention of study methods).

In an experiment with a row of ten 25-foot white pines protecting the west wall of a New Jersey townhouse from prevailing winds during part of a winter, a 3% seasonal heat savings by reduced air exchange was projected (31). This savings is atypically low because only one wall was exposed, and the wall was also protected by a 5-foot-high wooden fence. In addition, savings would also have occurred in at least two adjacent units, and large window areas on the first floor would have been shaded by the trees in late afternoon in summer to add to savings.

In studies in central Pennsylvania, a moderately dense single-row white pine windbreak reduced heat energy use in a single mobile home by about 12%. The largest savings occurred with the mobile home 1 or 2 tree heights from the windbreak (12). However, a one-row, 18-foot-tall spruce windbreak along part of one side of a mobile home park did not produce measureable reductions in energy use—partly because the added windbreak reduced windspeed by only 9% or less (some existing trees already reduced the wind), partly because the closest mobile home was 3 tree heights from the windbreak, and partly because different occupant behavior between the 2 years of measurement influenced energy use considerably and obscured any windbreak effect (54).

Data collected in full-scale occupied houses in Radisson, New York, (42) suggest savings in heating energy of more than 20% by wind protection; but study methods and assumptions are not presented in detail.

For an average frame house, air infiltration produces about one-third of the winter heat loss. Hence, a 50% reduction in air infiltration—probably the maximum possible with windbreaks on all sides—would lead to about a 17% savings in heating fuel. In typical houses of conventional construction that are in exposed locations, it seems reasonable to expect a 10 to 12% savings potential for windbreaks, similar to the 10% estimate by Flemer (15) for a house in New Jersey with a white pine windbreak.

Table 2. Reported energy savings by windbreaks, in percent of heat used by an unprotected house.

Model buildings in N.D. (3)	23-40
Models in wind tunnels	
In Kans. (55)	15
In N.J. (20)	9
Individual unoccupied mobile home in Pa. (12)	12
Occupied full-scale houses	
Townhouse in N.J. (31)	3
Detached house in N.J. (15)	10
Detached houses in Radisson, N.Y. (42)	25
Windbreak around mobile home park in Pa. (54)	NM*

*NM = not measurable

Shade trees. On a percentage basis, trees can provide large savings in energy for air conditioning (Table 3). For mobile homes, savings may be somewhat greater than for conventional homes. Percentage savings are larger in cooler climates. For example, in central Pennsylvania, a 75% savings resulted from complete shade over a mobile home in a deciduous grove. In this climate, most of the air conditioning load in sites without shade is caused by solar input rather than warm air temperatures or very humid air, and tree shade removes most of the solar input. However, the amounts of energy and dollars saved are larger in warmer climates where more air conditioning is needed.

Tree shade is also effective in reducing temperatures of interior air and walls—up to 20°F in one uninsulated structure (Table 4). Reductions of temperature in full-size, ventilated, insulated houses are smaller than reductions in closed test units. Tests with model houses with closed windows and no natural ventilation are useful for comparing relative effects of different degrees of shade. For example, shade of Norway maple was more effective in reducing interior air temperatures than shade of honeylocust (36).

Shading of air conditioning units may also save considerable energy. One study (41) suggested a 10% increase in air conditioning efficiency in the vicinity of Miami, Florida.

Combined shading and wind reductions. The net annual effect of trees on energy use is approximately equal to the sum of radiation reduction effects in summer (save energy), wind reduction effects in winter (save energy), and shading effects in winter (waste energy). The few estimates of energy effects of trees over the course of a year range from a 24% saving for the completely shaded mobile home in a deciduous tree grove in Pennsylvania to a 25% (\$88) increase in energy use with a solar home shaded by a row of 40-foot-tall deciduous trees 15 feet to the south (Table 5).

For the mobile home in Pennsylvania (Table 5), heating energy use was unchanged or perhaps slightly greater in the daytime because the trees reduced solar radiation by 37%. At night, however, the 40% reduction in windspeeds by the deciduous tree grove caused lower air exchange, and the net effect was an estimated 8%

reduction in seasonal energy use. The mobile home was completely shaded beneath the closed tree canopy, whereas full-scale homes in forest sites would usually be less shaded in summer because the clearing for the house would be larger. However, judicious thinning could allow more sun on a house in winter than was on the mobile home, while only slightly reducing summer shade. Although a small mobile home does not

Table 3. Reported energy savings from shade of trees in summer, as percent of air conditioning energy use by an unshaded house.

	%
Computer modeling	
Heavy shade on all walls and roof of a concrete block house in Fla. (5)	19
"Optimally landscaped" trailer on July 23 in Ga. (4)	52
Shade of mature tree canopy on small test house in Davis, Calif. (33)	10-40
Shade on N, E, and W sides of well-insulated house in Chesapeake, Va. (8)	11
Measured in mobile homes	
Dense shade by a deciduous grove in Pa. (13)	75
Landscape trees in Fla. (41)	40
Partial tree shade in Ala. (30)	59
Shaded conventional houses in Tex. (44)^a	11-24

a I made the assumption that winter electricity bills represented energy use for purposes other than space conditioning.

Table 4. Reported reductions in interior air temperatures (°F) of houses or model houses by complete tree shade.

One-eighth scale model house with realistic insulation and thermal mass but not ventilated in Utah (36)	13
Lived-in houses surveyed in Calif. Central Valley (7)	
Insulated	2
Not Insulated	6
Wood-frame trailer, uninsulated, not ventilated, tree shade in Calif. (9)	20

have the structure of a conventional house, tree effects on the mobile home, expressed as percentages, were thought to be similar to effects on a conventional house because in this mobile home, the proportion of conductive heat losses to air-exchange heat losses was typical of conventional construction.

Trees, including deciduous trees, that shade solar apertures (such as solar collectors or large south-facing windows with a means of insulating at night) to any significant degree will generally be economically detrimental over a year (22, 47, 48, 49).

The effect of trees on annual energy use averaged over all of the dwellings of neighborhoods, given the rather random tree and house arrangements that seem to exist in most communities, is usually a matter of conjecture. In climates where energy costs are greater for cooling than for heating, the net annual effect of trees will be decidedly beneficial, ^{because} even if reductions in winter wind are negligible, reductions in radiation over the winter will not increase energy use more than reductions over the summer, assuming random tree arrangements. For example, in College Station, Texas, tree shade apparently caused average reductions in air conditioning use of up to 24% (Table 3). The effect of trees in winter was not evaluated, but the year-round effect on heated and air-conditioned buildings would be positive because College Station has more need for air conditioning (about 2,900 cooling degree days) than for heating (only 1,700 heating degree days), assuming that the degree days reported by NOAA (39) are indicative of air conditioning and heating energy use. (Heating or cooling degree days are calculated for each day as the difference between mean outdoor temperature and 65°F.)

For houses in neighborhoods with cool climates, such as in Truckee, California, the direction of the aggregate annual effect of existing trees seems less certain. A row of deciduous trees on the south was predicted to cause a 4% increase in energy use in a conventional house in this climate with few cooling degree days (Table 5). However, random tree and house arrangements should cause less detrimental shade in winter than a solid row of 40-foot trees just 15 feet to the south. Wind reductions by trees, which

we have seen might be about one-third in residential areas, might yield heat energy savings that would exceed increased energy use by shading.

Locating and Managing Trees for Saving Energy

Consider the whole year. Despite uncertainties about the exact amount of energy that trees may save in particular situations, suggestions can be made for selecting and locating trees to create energy savings. The key is to consider effects of trees year round. For conventional houses without solar collectors, maximizing summer tree shade without regard to negative effects of winter shade by the same trees may be a good strategy in very warm climates (41), and probably in temperate climates where installation of air conditioning can be avoided.

In any nontropical climate, trees that shade in winter but not in summer are likely to be detrimental. A small amount of tree shade in winter may be balanced by wind reductions by the trees. Trees some distance to the south shade only in winter (Fig. 6); and because winds are from the south

Table 5. All-year effects of trees on energy use for heating and cooling. Energy use is for houses with vegetation compared to the same house in a large open space.

Study	HDD-CDD ^a	Energy use ^b	
		%	\$
Measured in mobile home			
In deciduous woodlot in central Pa. (13)	+5280	-24	—
Computer modeling results			
Heavy deciduous shade on one-story frame house in Orlando, Fla. (5)	-2490	-15	-128
Row of trees 15 feet to south in Calif. (48)			
Conventional house			
Palm Springs	-2440	- 7	- 60
Truckee	+8170	+ 4	+38
Solar house			
Palm Springs	-2440	+ 1	+ 5
Truckee	+8170	+25	+88

^aHeating degree days minus cooling degree days; negative numbers indicate more energy needed for cooling than for heating.

^bMinus signs indicate energy saving; plus signs indicate more energy use.

only for a small proportion of winter in most locations, benefits from wind reduction will probably be small for trees in that direction. The net effect of trees on the north, east, and west is generally positive.

Tree location plans similar to Figure 7 are usually recommended for saving energy in conventional houses in temperate climates (35, 37, 43). In winter, winds are most often from the north, northwest, and west; and these are blocked by a windbreak on those sides. Shade trees are located to the west, northwest, and east. Trees to the south (particularly conifers) would be not taller than about one-half the distance to the house (at about 40° latitude) or would be close to the house and have the lower bole pruned to allow the sun to reach south walls in midwinter.

These conceptual plans illustrate the general principles, but in the real world, houses come in

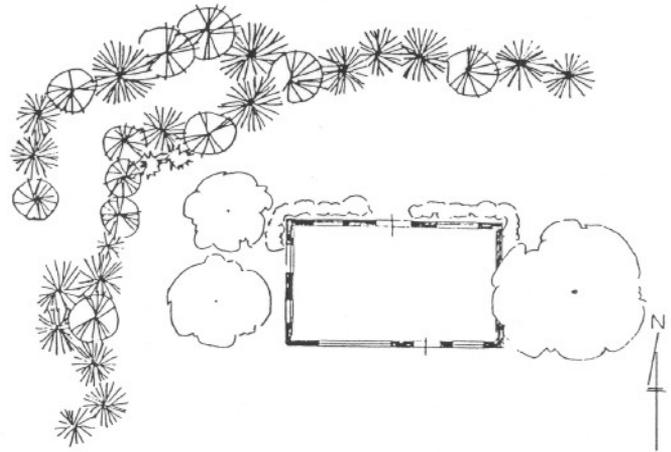
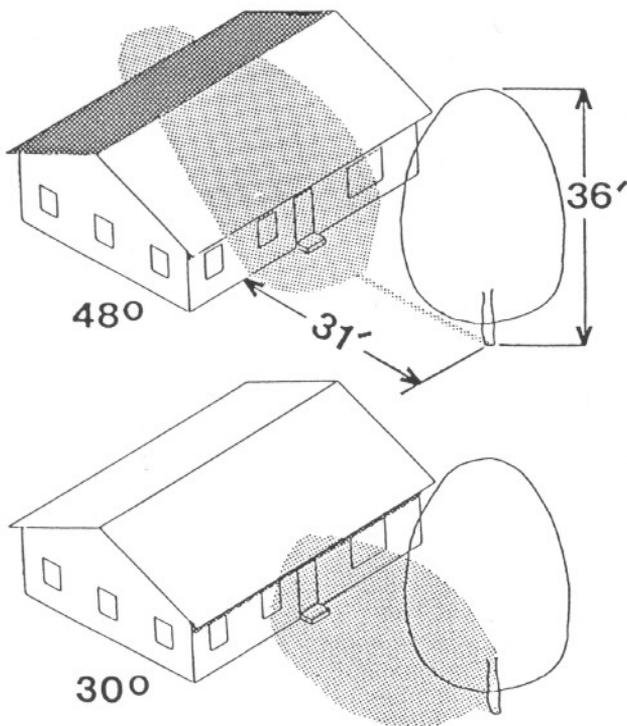


Figure 7. Optimum landscape concept for a temperate climate with winter wind predominantly from the west and northwest.

many shapes and sizes, are built to different construction standards, are placed on lots of various sizes and at various orientations to sun and wind, and have neighboring houses and trees at various distances. Particularly in planning for shade, customizing of tree management with some tools and analysis may be necessary.

Planning shade. A simple tool for shade planning that arborists might use is the solar path diagram (Fig. 1). These are available for each 4 degrees of latitude (32). The diagrams give a general intuitive impression of how to manage trees for shading and show the times when a tree will shade a particular point of a house. Shade on windows is especially important. Determining how a window is shaded by an existing tree throughout the year can be done by standing at a point near the middle of the window and sketching in the tree outline on a copy of the solar diagram. Angles can be estimated or measured with a compass and clinometer. Plastic overlays for the diagrams are available to indicate amounts of radiation from the sun at different points in the sky for clear days (32). Data from the diagrams can also be used to find the length and direction of tree shadows on the ground. Shadow length is obtained easily with a scientific pocket calculator (tree height divided by TAN of sun elevation angle). Other devices for evaluating shade on individual points were reviewed by Solar Age (46).

A shortcut to shade planning is to select design



SHADE FOR JANUARY 21. NO SHADE ON HOUSE APR–AUG

Figure 6. Patterns of tree shade in midwinter (Jan. 21) at 30° (New Orleans) and 48° latitude (Grand Forks, N.D.) with tree 19 feet farther south of the house than in Figure 5. The tree in this position would not shade the house from April through August at either latitude.

dates to plan for maximum shade at the warmest part of the year and minimum shade at the coldest. July 21 and January 21 are appropriate dates for most of the country. For cities in warmer climates influenced by oceans, such as Los Angeles, Miami, Orlando, and New Orleans, an early- to mid-August design date is more appropriate.

There are other shade-planning techniques. Computer programs are available to assist in shade planning. One of these plots obstacle heights required for shading windows on particular dates (52). This program is available in BASIC and FORTRAN 77 from J. Alan Wagar, Pacific Southwest Forest and Range Experiment Station, P. O. Box 245, Berkeley, California 94701. The program is easy to install and use interactively on either a mainframe or on an IBM PC computer, though interpretation of results requires some study. For 11 Florida locations, solar azimuth angles and shadow lengths have been tabulated along with suggestions for their use in evaluating tree shade (6). Scale models of buildings and trees with a small sundial and a lamp to represent the sun can be useful in shade planning. This technique was used to prepare Figures 5 and 6. Cardboard sundials and a description of the modeling technique are available from this author.

Planning windbreaks. A few suggestions for planning and managing windbreaks are offered here (see also reference 24). In windbreak trees, rapid growth is generally more important than high density. Close spacing of trees within windbreak rows increases early effectiveness and may increase height growth. A 6-foot spacing is not too close for most species. Some, such as arborvitae, should be closer. Trees in two or more rows will be more effective if widely spaced between rows. Single-tree rows can be about as effective as multiple rows provided the trees are closely spaced. Pruning lower branches can increase air exchange in buildings (20). Windbreaks should be fairly close to houses—about 50 feet seems a good distance; a smaller distance generally would be more effective than a much greater distance (12). Where drifting snow is a problem, a row of shrubs upwind of the windbreak can help.

Windbreaks will be most effective on the side of the house in the direction of prevailing winter

winds. For many cities, summaries of wind speed and direction by month are available from the National Climatic Center in Asheville, North Carolina (704-259-0682, ext. 683).

Further information. For professionals seeking additional information, one good source is a recent book, "Energy-Conserving Site Design" (35). Other starred items in the reference list may also be of special interest to arborists. The September 1984 *American Forests* carries a concise overview of tree effects on energy use (28), and tree effects on local climate and energy use are summarized by Harris (22).

Use caution in following some publications on energy savings with trees. One widely distributed extension bulletin illustrates summer and winter shade of deciduous trees with identical sun angles for both seasons. No mention is made of possible deleterious shade by deciduous trees in winter. A "typical planting plan" shows trees on the south too far from the house to provide much summer shade.

Summary and Conclusions

Trees have major effects on both solar radiation and wind, and they do affect energy use in buildings. But trees around buildings do not always save energy. It might better be said that proper management of trees saves energy. In general, it appears that for detached houses of conventional construction, trees in an optimum arrangement could save 20 to 25% of annual space conditioning energy use compared to the same house in an open field.

There are obstacles to tree management for energy saving. The amount of energy used in houses depends on many factors that may overshadow even fairly sizable energy savings with trees. While the effects of insulation, caulking, and other energy-saving modifications to building structures are relatively large (savings of 50% have been claimed), immediate, and easily determined and documented, testing tree effects is difficult. Vastly more research has been done on building structural effects than has been done on tree effects on energy use. Available design guides reflect this discrepancy. And there are no tax incentives for tree management for energy saving.

For all of these reasons, an arborist might be reluctant to spend time thinking about the energy consequences of planting, removing, or pruning trees with all the other concerns of tree care. However, few homes have trees in positions approaching the optimum for energy efficiency. Arborists who can offer advice about tree effects on energy use will be providing a valuable service. It would seem that clients could be convinced to take their business to the energy-knowledgeable arborist.

Acknowledgments. The following individuals provided helpful review comments on an earlier draft: David DeWalle, Greg McPherson, Robert Thayer, J. Alan Wagar, and David J. Ziegler. Stephen B. Gleason assisted with data analysis and preparation of figures.

Literature Cited

1. American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). 1977. ASHRAE Handbook—1977 Fundamentals. ASHRAE, New York.
2. Arens, E. A., and P. B. Williams. 1977. *The effect of wind on energy consumption in buildings*. Energy and Build. 1:77-84.
3. Bates, C. G. 1945. *Shelterbelt influences II. The value of shelterbelts in house heating*. J. For. 43(3):176-196.
4. Bray, R. K. 1982. Effectiveness of vegetation in energy conservation. Master's thesis, University of Georgia, Athens, GA. (Cited in McPherson, 1984a).
5. *Buffington, D. E. 1981. *Economics of residential landscaping for energy conservation—a statewide program*. Proc. Florida State Hortic. Soc. 94:208-216.
6. *Buffington, D. E., S. K. Sastry, and R. J. Black. 1981. Factors for Determining Shading Patterns in Florida. Florida Coop. Ext. Serv., Inst. of Food and Agric. Sci. (A series of circulars numbered 505 through 516.) 27 pp. each.
7. Cramer, R. D., and V. G. Kay. 1958. *Temperature control for houses. VI. Temperature control practices*. J. Home Econ. 50(3):181-184.
8. Center for Landscape Architectural Education and Research (CLAER). 1981. Site and Neighborhood Design for Energy Conservation: Five Case Studies. (ANL/CNSV-TM-99). Argonne Natl. Lab., Argonne, IL. 581 pp.
9. Deering, R. B. 1955. *Effective use of living shade*. California Agric. (September 1955). pp. 10-11, 15.
10. *DeWalle, D. R. 1978. Manipulating urban vegetation for residential energy conservation. In: G. Hopkins, ed. Proceedings of the National Urban Forestry Conference (Vol. 1, ESF Pub. 80-003). SUNY Coll. Environ. Sci. and For., Syracuse, NY. pp. 267-283.
11. *DeWalle, D. R. 1982. Energy conservation through urban forestry. In: Proc. 2nd Natl. Urban For. Conf., Cincinnati, Ohio. Am. For. Assoc., Washington, DC. pp. 119-123.
12. DeWalle, D. R., and G. M. Heisler. 1983. *Windbreak effects on air infiltration and space heating in a mobile home*. Energy and Build. 5:279-288.
13. *DeWalle, D. R., G. M. Heisler, and R. E. Jacobs. 1983. *Forest home sites influence heating and cooling energy*. J. For. 81(2):84-88.
14. *Federer, C. A. 1976. *Trees modify the urban microclimate*. J. Arboric. 2(7):121-127.
15. *Flemer, W., III. 1974. *The role of plants in today's energy conservation*. Am. Nurseryman 89(9):10, 39-45.
16. *Foster, R. S. 1978. Homeowner's Guide to Landscaping that Saves Energy Dollars. David McKay, New York. 183 pp.
17. Gardner, T. J., and T. D. Sydnor. 1984. *Interception of summer and winter isolation by five shade tree species*. J. Am. Hortic. Soc. 109(4):448-450.
18. *Halverson, H. G., S. B. Gleason, and G. M. Heisler. In press. *Leaf duration and the sequence of leaf development and abscission in Northeastern urban hardwood trees*. Urban Ecol.
19. Hans, G. E. 1980. Streamlined heating energy budget analysis for solar-oriented house design. Paper presented at University of Wisconsin—Extended Program on Passive Solar Building Design, November 1980, Madison, WI. 22 pp.
20. Harrje, D. T., C. E. Buckley, and G. M. Heisler. 1981. *Building energy reductions: windbreak optimization*. J. Energy Div., Am. Soc. Civ. Eng. 108(EY3):143-154.
21. *Heisler, G. M. 1977. *Trees modify metropolitan climate and noise*. J. Arboric. 3(11):201-207.
22. *Harris, R. W. 1983. Arboriculture. Prentice-Hall, Englewood Cliffs, NJ. 688 pp.
23. Heisler, G. M. 1982. Reductions of solar radiation by tree crowns. In: The Renewable Challenge, Proceedings of 1982 Annual Meeting of the American Section of International Solar Energy Society, Houston, TX. Am. Solar Energy Soc., Boulder, CO. pp. 133-139.
24. *Heisler, G. M. 1984. Planting design for wind control, chapter nine. In: E. G. McPherson, ed. Energy-Conserving Site Design. Am. Soc. Landscape Archit., Washington, DC. pp. 165-183.
25. Heisler, G. M. 1985. Measurements of solar radiation on vertical surfaces in the shade of individual trees. In: Hutchison, B. A. and B. B. Hicks, eds. The Forest-Atmosphere Interaction: Proceedings of Forest Environmental Measurements Conference, October 23-28, 1983, Oak Ridge, TN. Reidel Publishing Co., Dordrecht, Holland. pp. 319-335.
26. Heisler, G. M. In press. *Effects of individual trees on the solar radiation climate of small buildings*. Urban Ecol.
27. *Heisler, G. M., and D. R. DeWalle. 1984a. *Managing urban forests for energy savings*. Natl. Urban and Community For. Forum 4(4). 2 pp.
28. *Heisler, G. M., and D. R. DeWalle. 1984b. *Plantings that save energy*. Am. For. 90(9):13-16.
29. Hutchison, B. A., F. G. Taylor, and the Critical Review Panel. 1983. *Energy conservation mechanisms and potentials of landscape design to ameliorate building microclimates*. Landscape J. 2(1):19-39.
30. *Laechelt, R. L., and B. M. Williams. 1976. Value of Tree Shade to Homeowners. Bull. 2450. Alabama For. Comm., Montgomery. 6 pp.
31. Mattingly, G. E., D. T. Harrje, and G. M. Heisler. 1979. *The effectiveness of an evergreen windbreak for reducing residential energy consumption*. ASHRAE Trans. 85(2):428-443.
32. *Mazria, E. and D. Winitzky. 1976. Solar Guide and Calculator. Cent. for Environ. Res., University of Oregon, Eugene. 16 pp.

33. McGinn, C. E. 1983. The microclimate and energy use in suburban tree canopies. Ph.D. dissertation, University of California, Davis. 299 pp.
34. McKeever, M. 1984. Solar Access Economic Feasibility Study for Portland Residences. Report to City Energy Office by Conservation Management Services, Portland, OR. 20 pp.
35. *McPherson, E. G., ed. 1984a. Energy-Conserving Site Design. Am. Soc. Landscape Archit., Washington, DC. 326 pp.
36. *McPherson, E. G. 1984b. Solar control planting design, chapter eight. In: E. G. McPherson, ed. Energy-Conserving Site Design. Am. Soc. Landscape Archit., Washington, D.C. pp. 141-164.
37. *Moffat, A. S., and M. Schiler. 1981. Landscape Design that Saves Energy. William Morrow, New York. 223 pp.
38. Nageli, W. 1946. *Weitere Untersuchungen über die Windverhältnisse in Bereich von Windschutzstreifen*. Mitt. Schweiz. Anst. Forstl. Kersuchsw. 24(2):659-737.
39. *National Oceanic and Atmospheric Administration (NOAA). 1981. Comparative Climatic Data for the United States Through 1980. NOAA Natl. Climatic Cent., Asheville, NC. 94 pp.
40. *Norman, J. M. 1984. The influence of trees on urban climate. In: Trees for Various Uses, Papers of 7th Annual Trees for Nebraska Conf., March 2 and 3, 1984. Nebraska Cent. for Contin. Educ., Lincoln. pp. 19-24.
41. *Parker, J. H. 1983. *Landscaping to reduce the energy used in cooling buildings*. J. For. 81(2):82-84.
42. Reimann Buechner Partnership. 1979. Energy Conserving Site Design Case Study—Radisson, New York. U.S. Dep. Energy Rep. DOE/CS/4212-T1, Washington, DC. 151 pp.
43. *Robinette, G. O., ed. 1983. Energy Efficient Site Design. Van Nostrand Reinhold, New York. 158 pp.
44. *Rudie, R. J., and R. S. Dewers. 1984. *Effects of tree shade on home cooling requirements*. J. Arboric. 10(12):320-322.
45. Sherwood, G. L., and G. E. Hans. 1979. Energy Efficiency in Light-Frame Wood Construction. Res. Pap. FPL 317. USDA For. Serv., For. Prod. Lab., Madison, WI. 58 pp.
46. *Solar Age. 1983. *Rating the site survey tools*. Solar Age 8(6):14-16.
47. *Thayer, R. L., Jr. 1983. *Solar access and the urban forest*. Arboric. J. 7:179-190.
48. *Thayer, R. L., Jr., and B. T. Maeda. 1985. *Measuring street tree impact on solar performance: a five-climate computer modeling study*. J. Arboric. 11(1):1-12.
49. *Thayer, R. L., Jr., J. Zanetto, and B. T. Maeda. 1983. *Modeling the effects of street trees on the performance of solar and conventional houses in Sacramento, California*. Landscape J. 2(2):155-165.
50. Thompson, W. 1984. Residential Energy Consumption Survey: Consumption and Expenditures, April 1982 through March 1983. DOE/EIA-0321/1(82). U.S. Dep. Energy, Washington, DC. 270 pp.
51. *Wagar, J. A., G. M. Heisler, and D. Atkinson-Adams. In press. *Rating winter crown density of deciduous trees: A photographic procedure*. Landscape J.
52. *Wagar, J. A. 1984. *Using vegetation to control sunlight and shade on windows*. Landscape J. 3(1):245-35.
53. Wagar, J. A. In press. *Trees for solar control*. Proc. 1985 National Convention of the Society of American Foresters, July 28-31, 1985, Fort Collins, CO. Soc. Am. For., Washington, DC.
54. *Walk, M. F., D. R. DeWalle, and G. M. Heisler. 1985. *Can windbreaks reduce energy use in a mobile home park?* J. Arboric. 11(6):190-195.
55. Woodruff, N. P. 1954. Shelterbelt and surface barrier effects on wind velocities, evaporation, house heating, and snow drifting. Kansas Agric. Exp. Stn., Manhattan. 27 pp.
56. Youngberg, R. J. 1983. *Shading effects of deciduous trees*. J. Arboric. 9:295-297.

*Indicates articles of greater interest for arborists.

Research Forest Meteorologist
 Northeastern Forest Experiment Station
 USDA Forest Service
 104 Academic Projects Building
 University Park, PA 16802