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Forest Home Sites Influence Heating And Cooling Energy

David R. DeWalle, Gordon M. Heisler, and Robert E. Jacobs

ABSTRACT — Experiments with small mobile homes in Pennsylvania indicated that shade of trees can significantly reduce solar heating and that by lowering wind speeds forests can lessen infiltration of outside air. In one deciduous stand in summer, cooling energy needs were 75 percent less than in the open. In winter shading is counterproductive, offsetting savings from reduced infiltration of cold air. In the deciduous stand, savings in winter heating energy were only 8 percent, and with greater shading in a dense pine forest heating energy needs rose 12 percent. Forests and windbreaks are especially effective with poorly sealed houses and in windy weather. On forested sites in most of the United States, energy use can probably be lessened by manipulating forest growth to allow the sun to strike the house in winter. On open sites windbreaks and carefully located shade trees would lessen year-round energy use.

Rising energy costs have caused homeowners to seek ways of reducing energy needs for space conditioning. Management of trees and other landscape vegetation offers one approach. By modifying the microclimate, the vegetation affects exchange of heat between a house and its environment.

Home heat exchange occurs through three basic processes: air infiltration, heat conduction through walls, roofs, and floors, and transmission of solar radiation through glass. Air infiltration is the passage of air into a structure through joints, pores, cracks, and other openings. Such flows result from pressure differences between inside and outside air. Pressure differences in turn may be caused by the force of the wind and by differences in temperature between inside and outside air. Wind velocity reductions by vegetation can reduce air infiltration significantly.

Shade from trees can lessen heat conduction and radiation transmission into a home primarily by reducing solar radiation reaching exterior surfaces. Wind velocity reductions by vegetation also reduce heat conduction, by lessening heat convected to and from exterior surfaces of buildings.

Information on the use and management of trees and forests to reduce energy requirements for home space conditioning has been developing in a number of studies dating back to about 1940 (see reviews by DeWalle 1980 and Heisler 1977). This article summarizes several experiments to determine effects of forest sites on energy use for summer cooling and winter heating of mobile homes. Forest sites are of particular interest because houses are often located in forests for esthetic reasons. The information from these experiments also indicates some effects of windbreaks and shade trees on energy use.

Study Methods

The basic approach was to measure energy requirements for several weeks with a mobile home at an open site with no shade or wind protection and then to move the mobile home to a forest site. Energy use during day, night, and 24-hour periods at the forest site was compared with use predicted for the same general weather at the open site. Predictions were made with regression equations relating energy use to wind velocity, solar irradiation, and the temperature difference between inside and outside air. Statistical significance of forest effects was evaluated by use of regression equation confidence limits for individual predictions and paired t-tests for measured and predicted means. The mobile homes were fully equipped camper types ranging in length from 5 to 6 m (*fig. 1*). Effects of locating in a deciduous grove were evaluated during the summer of 1976 and winter of 1977, and effects of a red pine (*Pinus resinosa*) plantation were studied in the winters of 1976 and 1977. Similar but not identical mobile homes were used in the two years. In one experiment, windows were opened a small measured amount to simulate loose construction.

The deciduous grove was about 2 hectares in size. It consisted primarily of dominant mature white oak (*Quercus alba*) about 24 m tall with an average d.b.h. of 45 cm and an understory of black cherry (*Prunus serotina*) 12 to 15 m tall and about 18 cm d.b.h. Basal area was about 24 m^2 per hectare. The mobile home was situated about 40 m from the nearest (west) edge. The canopy was closed at this site.

In the red pine plantation, the mobile home was in an opening of 6 m by 15 m, but an approach road prevented the canopy on the south side from being completely closed. The trees were approximately 21 m tall with an average d.b.h. of 23 cm and a basal area of 55 m^2 per hectare.

The predictions of energy use for the open site in each experiment required that weather be measured at both sites. Hygrothermographs in standard weather shelters recorded temperature and humidity. Radiometers with battery-operated integrators measured solar radiation on horizontal surfaces. In the forest, the radiometer was on the roof of the mobile home; in the open it was on top of the weather shelter. Anemometers measured wind speed 2 m above ground at both forest and open sites. Prevailing winds in the region are from southwest to west directions.

Figure 1. One of the small mobile homes used in research into effects of forests on heating and cooling energy loads.

windows were opened slightly to simulate loose construction. With the windows closed there was no significant change in average 24-hour energy use in 1976; and in 1977 there was a 23-percent increase. Seasonal energy use predictions indicated somewhat less forest effect than was measured during the experimental periods; but the 1977 seasonal increase was still 12 percent, and the reduction with windows opened slightly in 1976 was 8 percent.

Heavier shade in the pine forest explains why energy use for heating was generally higher than at the deciduous site in winter (*fig. 3*). The pine forest in 1976 reduced solar radiation on the mobile home by 72 percent compared to the open, while reduction in the deciduous grove was 37 percent. This was the primary reason for the 7-percent energy savings in the deciduous grove and essentially no change in the pine forest.

Forest Effects On Winter Air Infiltration

Winter air infiltration rates were generally decreased at all forest sites (*fig. 4*). The magnitude of the reduction is related to the effect on wind velocity, climatic conditions, and the leakiness of the mobile home. Leakiness is indicated by the percentage of total heat exchange that is due to air infiltration.

Figure 5 gives the relationship between winter air infiltration rates and wind velocity for the mobile home used in 1977. At low wind velocities (less than 3.0 meters per second), winter air infiltration is primarily dependent upon the temperature difference, ΔT, between inside and outside air; and reductions in wind velocity would have a small effect on air infiltration. In fact, slight air temperature reductions caused by the

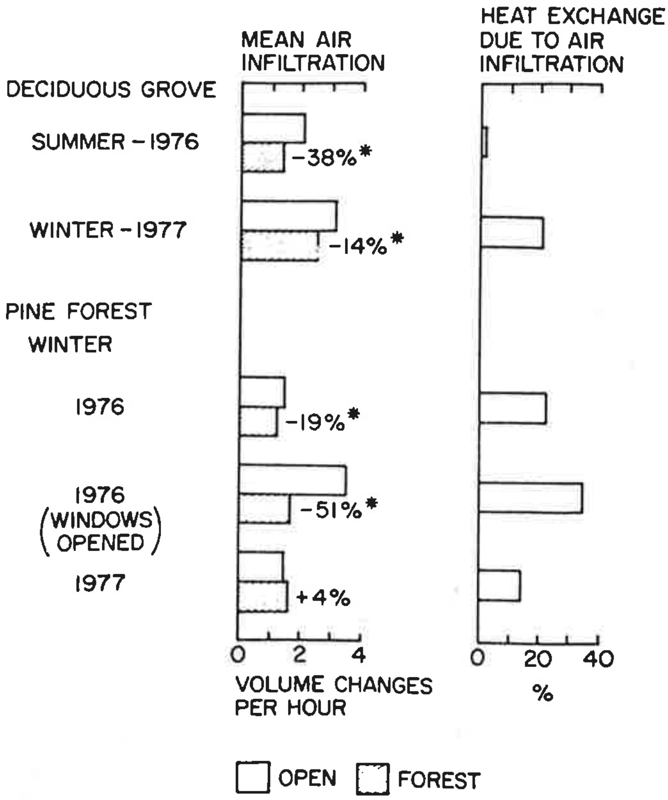

Figure 4. Forest effects on mean air infiltration rates and the percentage of home heat exchange attributable to air infiltration. Statistically significant changes in air infiltration are marked with an asterisk.

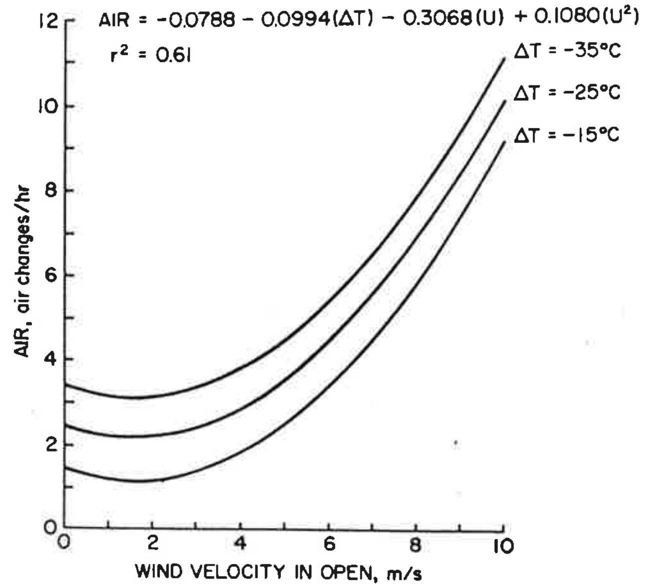

Figure 5. Relationship between winter air infiltration rate (AIR) for the mobile home used in 1977 experiments and the wind velocity (U) and the temperature difference between inside and outside air (ΔT).

forest could increase ΔT enough to more than offset effects of the forest on wind at low velocities. Higher wind velocities markedly influence air infiltration and velocity reductions caused by the forest can be highly effective in reducing infiltration.

Given the relationship between air infiltration and climate for 1977, forest effects in the mobile homes would be greatest at windy sites or when air temperature differences were small. Thus at the deciduous grove, where wind velocity in the open averaged higher than in any other experiment (*fig. 3*), a 40-percent reduction in velocity lowered infiltration rates by 14 percent. In contrast, infiltration rates were largely unaffected by a 74-percent reduction in wind velocity in the 1977 pine forest test, because velocities in the open were below the threshold for significant forest effects.

The fraction of total heat loss caused by air infiltration is an important house characteristic in determining the effectiveness of vegetation in controlling heat exchange. The 1976 experiment was designed to evaluate this effect. With the windows closed, a 73-percent reduction in wind velocity produced a 19-percent reduction in air infiltration rates. But when the windows were opened slightly to simulate loose construction, the forest caused a 51-percent reduction because the "loose construction" caused very high infiltration rates in the open.

Other Dwelling Types

Although the general percentage effects of the forest sites in these experiments should be valid for a wide range of dwellings, absolute magnitudes of energy needs and air infiltration rates apply only to small mobile homes. Heat conduction rates in the mobile homes were greater than in a full-sized home because of differences in wall construction, the absence of an attic, and smaller ratio of interior surface to interior volume. Air infiltration rates were also higher because of a larger ratio of crack length around doors and windows. However, the ratios of air infiltration heat losses to total heat losses for the small mobile homes are similar to the 33-percent rule of thumb for full-sized homes (Malik 1978). Thus, Energy use was monitored with running-time meters on electrical resistance heaters and air conditioners. Predicted and measured energy requirements were compared for day, night, and 24-hour periods. Daytime periods extended from 0800 to 2000 hours (local standard time) and nighttime periods extended from 2000 to 0800 hours in 1977. In 1976, daytime periods extended from 0900 to 1700 hours and nighttime from 1700 to 0900 hours. Each test lasted between 14 and 37 days.

To evaluate the importance of heat exchange processes as affected by forests, we measured air infiltration in the mobile homes, using a water vapor mass balance method described by DeWalle and Heisler (1980).

The energy use equations we developed for the mobile homes can also be applied to estimate the total energy savings which would result from forest protection for an entire heating or cooling season. We made such estimates for central Pennsylvania by collecting data on wind velocity, solar irradiation, and air temperature through each heating or cooling season at an open site near University Park. With this climatic data and the prediction equations, the energy necessary to heat or cool the mobile homes for each day was predicted and summed to get energy use in the open for an entire season. Similarly, seasonal energy use in the forest sites was predicted from the open-site wind and radiation values adjusted by the measured percentage reductions in wind and radiation at the forest sites.

Forest Effects on Summer Cooling

The deciduous grove was quite effective in altering energy requirements for air conditioning. It reduced energy needs for cooling by 80 percent during a 37-day test period, and the estimated seasonal saving was 75 percent (*fig. 2*). Statistically significant reductions occurred during 14 of 23 daytime test periods.

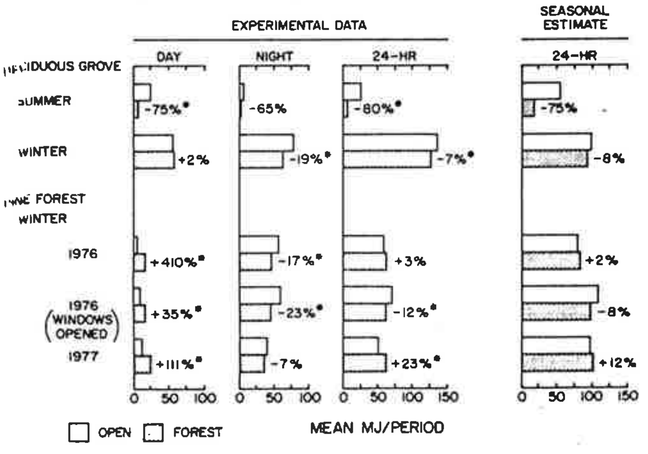

Figure 2. *Forest effects on energy needs (expressed in megajoules per day, night, or 24-hour measurement period) for summer cooling and winter heating. Percentage changes caused by the forest are marked with an asterisk when they are statistically significant (0.05 level).*

THE AUTHORS—David R. DeWalle is professor of forest hydrology, School of Forest Resources, Pennsylvania State University, University Park 16802. Gordon M. Heisler is research forest meteorologist, Northeastern Forest Experiment Station, USDA Forest Service, University Park, Pennsylvania. Robert E. Jacobs is executive assistant, Northumberland County Conservation District, Sunbury, Pennsylvania 17801. Research supported by Consortium for Environmental Forestry Studies, Northeastern Forest Experiment Station.

Essentially all of the reductions could be attributed to shading (*fig. 3*). Energy needs for cooling at night were small (*fig. 2*). Daytime periods with significant reductions were sunny and warm, while periods without reductions were overcast or partly cloudy and cooler. Daytime reductions were achieved because solar radiation reaching the roof was 91 percent less than in the open.

The deciduous grove reduced wind velocity by 62 percent (*fig. 3*) in the summer relative to the open, and this led to a 38-percent reduction in air infiltration (*fig. 4*). The infiltrating air, however, was usually not much warmer than interior air, and thus caused little heat gain.

In very hot climates, where a large portion of the air-conditioning load is due to high air temperatures and high humidity, reductions in wind velocity by forests may be considerably more important than in this study.

Forest Effects on Winter Heating

Deciduous grove.—During a 20-day heating experiment, the deciduous grove decreased energy needs by an average of 7 percent; predicted seasonal savings were 8 percent. Winter energy savings in the deciduous grove occurred at night when energy needs were reduced by 19 percent, but mean daytime energy needs were not significantly changed (*fig. 2*). Absolute values of energy use were higher in the deciduous grove than for the other sites primarily because of colder temperatures during the experimental period.

The energy savings at night can be attributed to reduced cold air infiltration. During the day, savings from reduced infiltration were offset by losses due to shade from the trees, which caused a 37-percent reduction in solar radiation on the house roof (*fig. 3*).

Pine forest.—In the pine forest, there was a tendency for heat energy savings at night, but average daytime needs increased (*fig. 2*). Energy-use reductions of 12 percent for 24-hour periods were realized in 1976 when

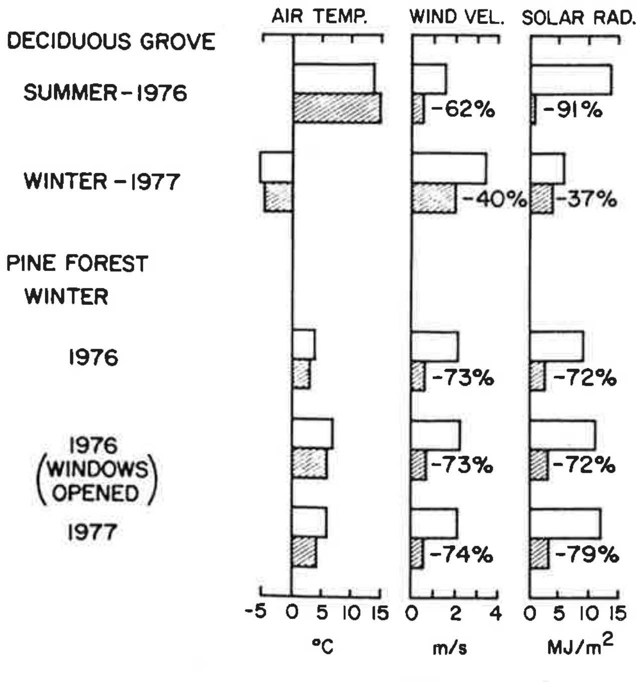

Figure 3. Effects of forest on average daily microclimate. Percentage changes caused by the forest are indicated.

proportionately, forest effects on heat conduction and air infiltration in the small mobile homes would be similar to effects on many full-sized homes.

Applications

Trees and forests around homes may significantly influence energy needs for summer cooling as well as winter heating. Depending on climatic conditions, forest type and arrangement of trees around the home, and the construction of the home, a forest may either increase or decrease energy needs. The mobile home experiments suggest some guides for managing trees to save energy on both forested and nonforested house sites.

Climatic conditions largely dictate how much energy is needed for summer cooling versus winter heating and thus dictate the primary emphasis of a vegetation management plan. In most mid-latitude regions, as in Pennsylvania, both summer cooling and winter heating must be considered. In the far northern part of the United States, primary emphasis is on energy savings in heating; and in the South primary emphasis would be on energy for cooling. Once a homeowner decides what the major objective for vegetation management will be, he or she can begin to assess the existing vegetation.

To secure maximum energy savings for summer cooling, complete forest shade would be desirable. Up to 80-percent reductions in energy needs for cooling seem possible in mobile homes through shading. Trees in a position to shade windows and the house surfaces responsible for major heat gains, such as roofs in mobile homes without attics or walls in conventional houses, would be most important. East- and west-facing surfaces are more important than south-facing surfaces. In warm climates some benefits may also be derived from reducing infiltration of hot, humid outside air.

Where heating energy is most important, maintenance of winter solar heating of the home and reduction in air infiltration should be of primary concern. Vegetation at a forest site should be managed to minimize shading of the home in winter. Where possible, trees should be removed if they shade the house at solar altitudes above the horizon of 15° to 40° typical of midday winter conditions in the northern United States. Even a leafless deciduous forest can intercept about 40 percent of the solar radiation reaching a home in the open. Dense conifers shading a house may increase heating energy needs up to about 10 percent.

Savings from reduced air infiltration will depend upon windiness of the climate, wind velocity reductions caused by the trees, and the leakiness of the house. In the tests, velocities at forest home sites were 40 to 80 percent below those in the open. Such velocity reductions lessened air infiltration by 4 to 51 percent depending on leakiness of the home. In Pennsylvania, energy savings for heating of about 10 percent are possible in a forest opening. At an open site nearly the same saving could be obtained with a properly located windbreak.

If a house uses significant energy for both winter heating and summer cooling, vegetation can be managed to provide shade in summer and little shade in winter. This is accomplished by removing trees or pruning the lower portions of crowns which would shade the house during midday in winter and planting trees, if necessary, for shade in summer. For homes with attics which insulate the ceiling and eaves which shade south-facing walls, shade for east-facing or west-facing walls should be provided in summer. In mobile homes without attics and eaves, summer shade is needed for the roof and south-facing walls too. Shade on windows should be given special consideration.

For most owners of existing houses, the easiest method of determining which trees to remove or prune would probably be to observe shade patterns on the house between about 9:00 A.M. and 3:00 P.M. on midwinter days. In general, this observation will show that trees on the east or west side of the house, on the south and with high crowns or trees close to the house overhanging the roof, will provide little winter shade. These trees will provide much shade in summer, when sun angles are different.

Estimates of year-round energy savings can be made from the 80-percent cooling and 10-percent heating energy savings indicated by our experiments. If 20 percent of total energy use for heating and cooling comes in summer, a value representative of parts of the Northeast, total year-round energy saving for heating and cooling through the use of vegetation should be approximately 24 percent. In southern regions, the percentage of cooling energy saving by trees would be less than in the Northeast, because a larger proportion of the total cooling requirement would be due to high air temperature and humidity, rather than to solar radiation. However, cooling energy is also a larger proportion of total heating and cooling energy use in the South, and year-round saving by vegetation might be larger than in the North. ■

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