From: "Trees and Sustainable Development," The Third International Windbreaks and Agroforestry Symposium Proceedings. June 2-7, 1991. Ridgetown, Ontario, Canada. Ridgetown College (Publisher).

# *COMPUTER SIMULATION FOR OPTIMIZING WINDBREAK PLACEMENT TO SAVE ENERGY FOR HEATING AND COOLING BUILDINGS*

*by: Gordon M. Heisler*

## PRESENTATION SUMMARY

Saving energy has recently acquired new importance because of increased concern for dwindling fossil fuel supplies and for the problem of carbon dioxide contributions to global climate change. Many studies have indicated that windbreaks have the ability to save energy for heating buildings. Suggested savings have ranged up 40 percent; though more commonly savings of between 10 and 25 percent are indicated (DeWalle and Heisler 1988). Questions remain as to how to best design windbreak plantings for different climates and building structures.

Previous studies of windbreak effects on energy use in buildings were done with a variety of methods. However, it generally was not possible to include windbreak effects on all the heat flows into and from a building over the course of a typical year and to compare the effects of windbreaks of different heights and densities at different distances and directions from a building. All of these variables may be considered using computer simulation.

This paper reports results of an initial set of simulations that were done partly to explore the potential of this tool to derive guides for optimum energy-saving windbreak design. The simulations used an existing energy analysis program that estimates the effect of all weather variables on heating and cooling energy requirements and costs in a building for each hour over the course of an entire year. Simulating tree effects on the weather variables requires submodels that are not part of the original program package. Similar methods have been used to study effects of other tree configurations on energy use in houses (Buffington 1978, Huang et al. 1990, McPherson 1987, Thayer and Maeda 1985), though tree effects on wind were modelled in less detail than in this study or were omitted.

In this study, the effects on energy use of a dense mature windbreak on both the north and the west at 50 ft. (15.2m) from a house are compared to the effects of a windbreak on the south at the same distance. The distance of 50 ft. was suggested as a desirable house to windbreak distance by Heisler and DeWalle (1984). North and west are the directions usually recommended for windbreaks, because prevailing wind directions are from those directions in much of the United States. There has been some concern that by shading the house in winter, trees on the south side might increase annual energy use in some climates (Heisler 1986, McPherson et al. 1988, Thayer and Maeda 1985).

The control case with no windbreaks was a house with no nearby trees or other obstructions. Hence the results pertain most directly to farmstead residences or suburban houses on large open lots. The model house was a simple one-storey ranch style with construction typical of single-family homes in the United States.

### Methods

The comparison of north and west windbreaks versus a windbreak on the south was carried out for seven locations in different climates (Figure 1). Heating degree days (HDD, base 65°F) ranged from about 3100 in Wichita Falls, Texas, to 9200 in Minot, North Dakota. Cooling degree days (CDD, base 65°) ranged from about 400 (Minot) to 2300 (Wichita Falls).

**Figure 1. Windbreak effects on energy use were simulated for these seven locations in the United States. The five most western locations are within the area of the Great Plains Shelterbelt project of the 1930's.**

### Energy analysis program

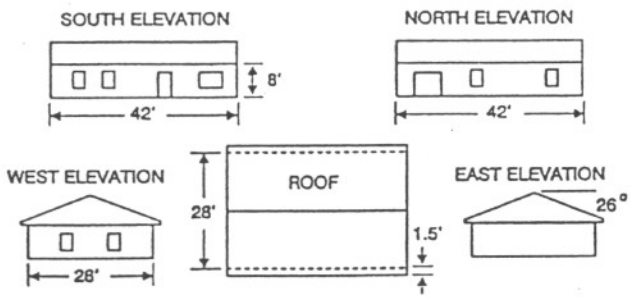
The energy analyses used a personal computer version of the program DOE 2.1D that was developed by the U.S. Department of Energy (LBL 1989). This program analyses heat flows into a building resulting from external weather conditions and calculates the fuel requirements for space heating or cooling and the total cost of these fuels over the course of a year. The program uses hourly weather data that is specially synthesized from long-term weather records. There are several possible sources of this data; we used Typical Meteorological Year data (NCC 1982) that is available for 234 cities in the United States. In most locations, the data are from an airport.

### Simulated house

The assumed house had 1176 ft.$^2$ (109m$^2$) of floor area, 3 inches (.08m) of fiber-glass insulation in walls and 5 inches (.14m) in the ceiling. Air tightness was average. Dimensions and window placement are shown in Figure 2. Double-pane windows occupied 12% of the wall area, and they transmitted 60% of the solar irradiance on them. Residents were assumed to not manipulate shades or drapes but to open windows half-way for ventilation when that was advantageous for cooling. Heat energy to the interior from people, lights, and appliances was

representative of occupancy by about 3 people every day of the year. The house was built on a concrete slab with insulation on the perimeter. Thermostat settings were 70° F (21.1° C) for heating and 78° F (25.6° C) for air conditioning. Cooling was provided by an electronically-operated central air conditioner of moderate efficiency; electricity cost was 6.5 cents per kilowatt hour. A natural-gas furnace provided heat; gas cost was $0.55 per 100,000 BTU.

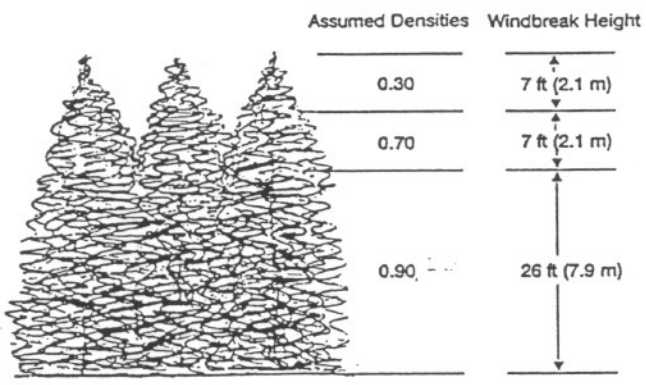
**Figure 2. Plan view of the roof and elevation views of the walls of the simulated house (1′ = 0.3048m).**




### Windbreaks

The windbreaks were assumed to be rows of mature conifers 40 ft. (12.2m) tall, with an optical density distribution that ranged from 90% in the lower 26 ft. (7.9m) to 30% in the upper 7 ft. (2.1m) as in Figure 3.

**Figure 3. Assumed distribution of density with height in the windbreak.**

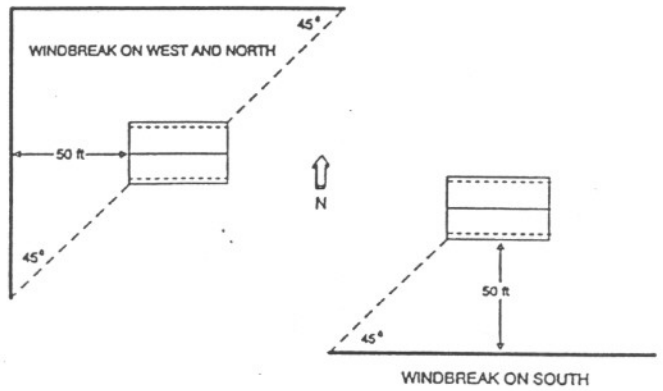



Such structures might result from a single row of closely-spaced dense conifers such as blue spruce *(Picea pungens* Engelm.), although with most conifer species, at least two rows would be required to provide this density. Windbreaks were assumed to extend 50 ft. beyond the corners of the house as in Figure 4.

### Effects on wind

Equations for modifying the weather data to represent windbreak effects on mean wind speed were derived in part by extrapolation of information from the literature (See Heisler and DeWalle 1988 for a recent review). However, because of the lack of measurements showing the complete horizontal pattern of wind flow for relatively short tree windbreaks with varying wind directions, some intuition was also required.

**Figure 4. Plan views of the house and windbreaks.**




With a long, narrow tree windbreak (height/width at least 1) and perpendicular wind direction, an optical density of 90 percent in the lower half of the windbreak will yield maximum reductions in mean wind speed of about 80% at about 1 windbreak height (1h) horizontal distance downwind of the windbreak. Wind reduction profile curves (Heisler and DeWalle 1988) with this maximum reduction suggest that at 50 ft., the house would experience a maximum reduction of about 75%. Windbreaks also provide some wind speed reduction for objects on their upwind sides. The curves suggest a maximum reduction of 15% at the house owing to the upwind effect.

Up to about 6h horizontal distance to leeward, the reduction in wind speed will not differ greatly with height between the ground and about 0.5h. With the windbreak height of 40 ft., wind reductions would be relatively constant with height over the 14 ft. of house height, given the windbreak to house spacing of much less than 6h.

In simulating wind parallel to a windbreak, I assumed neither reduction nor acceleration. For points close to long vegetative windbreaks, there is some reduction in wind speed even with parallel winds, because of the roughness of the windbreak vertical surface. However, near the upwind ends of windbreaks in parallel flow there may be increased wind speed. I assumed that the house was sufficiently distant from the windbreak for these two effects to be negligible or to cancel.

Even with long windbreaks, patterns of wind reductions change in a nonlinear way with wind direction. However, with windbreaks of limited length and the zone of interest at the house in our simulations, these nonlinear effects probably are small relative to effects caused by the geometry of the house and windbreak. Hence, I extrapolated linearly between the condition of no protection and full house protection.

Wind direction fluctuates about the mean. Because a series of measurements in another study (Heisler 1990) suggested 20° as a typical value of the standard deviation of wind direction, I assumed that wind effects extended out to 20° from the mean. In reality, the standard deviation varies

considerably with atmospheric conditions.

The assumptions in the previous paragraphs led to the patterns of relative wind speed at the house that were used to modify input weather data for energy analysis (Figure 5).

**Figure 5. Patterns of assumed relative wind speed at the house as a function of mean direction (azimuth from north) from which wind was blowing.**

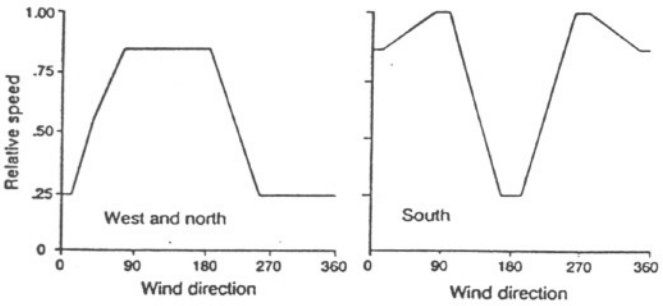
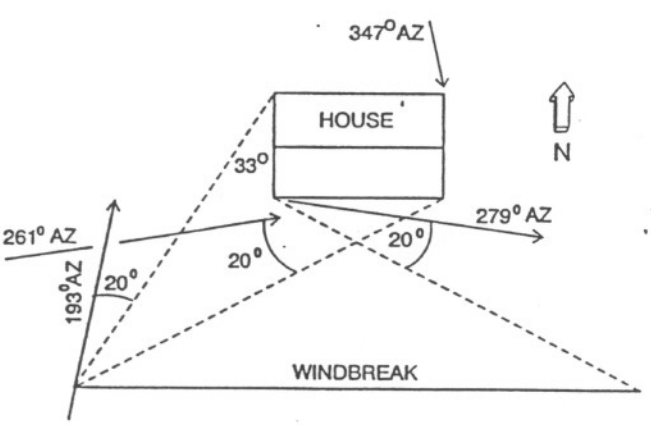



Figure 6 illustrates angles and azimuths used in deriving relative wind speed for the windbreak on the south. Starting with wind from the south, 180°, the house is assumed to be fully protected and relative wind speed is 0.25. As wind direction increases slightly, the fluctuations in wind direction cause the house to be less protected. I assumed this would begin to occur at 193°, because at this point, winds that deviate more than 20° from the mean direction bypass the windbreak to affect the house. Beyond 193° windbreak protection decreases and relative wind speed increases to 1.0 at 261°. By 279°, the upwind effect of the windbreak begins to reduce relative wind speed. The upwind effect is complete with an 85% relative wind speed at 347°. Similar methodology was used between 0° and 180° and for the windbreak on the north and west.

**Figure 6. Pertinent angles and azimuths for deriving relative wind speed at the house for the windbreak on the south as in Figure 5. See text for explantation.**



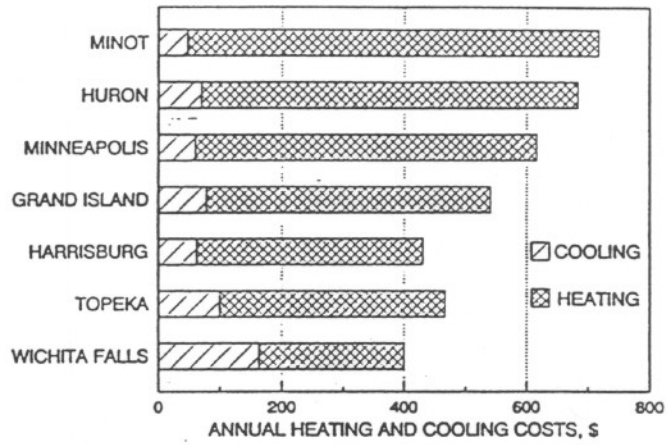

## Modelling effects on solar irradiance

DOE 2.1D has a provision for simulating shade on buildings, but only if the shading object can be described as a rectangular plane shape. The object may be assigned varying transmissivity to solar radiation. I modelled the shade effects of the windbreaks as vertical surfaces at the midline of the windbreaks, with assumed transmissivities equal to one minus the optical densities (Figure 3).

## Results

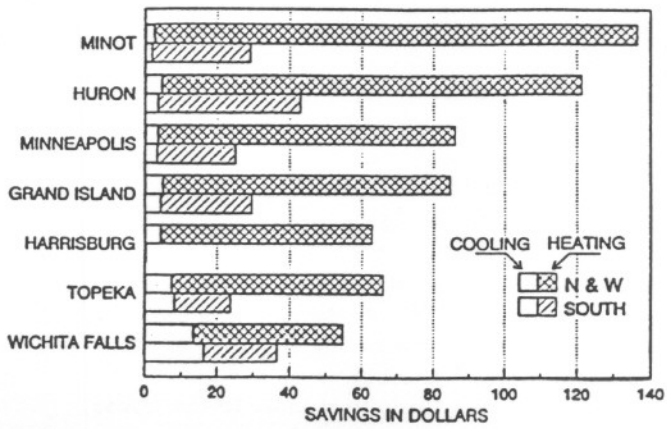
Without windbreaks, total space conditioning costs ranged from $400 in Wichita Falls to $717 in Minot (Figure 7). Heating costs were larger than cooling costs in all locations. As a percentage of total space conditioning costs, heating costs ranged from 59 percent in Wichita Falls to 93 percent in Minot. In the following discussion, results are presented in terms of cost and cost percentages, rather than quantities of electricity or gas, because cost is more directly applicable by home owners.

**Figure 7. Total simulated costs for heating and cooling the house without windbreaks.**




With windbreaks on the north and west, annual savings for heating and cooling ranged from 14% ($55) in Wichita Falls to 19% ($137) in Minot. For windbreaks on the south, savings ranged from negligible in Harrisburg to a percentage high of 9% ($36) in Wichita Falls and a dollar high of $43 (6%) in Huron (Figures 8 and 9). Most of the savings were for heating costs. However, in the warmest climate, Wichita Falls, cooling savings were also significant at 3.5% ($14) with the north and west windbreak and 4.3% ($17) with the south windbreak.

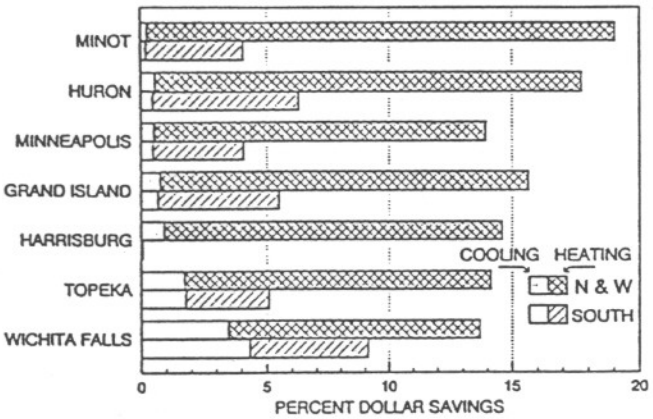
**Figure 8. Simulated savings in cooling and heating costs by the windbreaks on the north and west (N & W) and on the south, relative to an unprotected house. Savings by the windbreak on the south in Harrisburg were negligible.**



Savings generally increased from warmer to cooler climates. The discrepancies from this trend are caused by differences in windbreak effectiveness owing to different wind and radiation climates. the cities in Figures 7, 8, and 9 are listed in order of increasing HDD from bottom to top.

The lack of savings by the south windbreak in Harrisburg occurred because reductions in solar irradiance in winter were not compensated for by reductions in wind speed throughout the year. Wind speed reductions by the windbreak led to air infiltration reductions that saved energy for both heating and cooling. In the Plains region, there is a stronger southerly component to wind directions in both summer and winter than in most of the northeast. The windbreak on the south reduced heating costs in all locations except Harrisburg, where it caused a slight ($2) increase.

**Figure 9. Simulated percent savings in annual energy costs for heating and cooling by windbreaks on the north plus west (N & W) and on the south, relative to an unprotected house.**




Savings would have been greater with longer windbreaks. A few extra simulations were run for different windbreak configurations in Grand Island. Windbreaks on the north and west saved 15%, whereas windbreaks on all four sides saved 20% of heating costs.

**Discussion**

The results of the computer simulations reported here confirm studies by other methods that windbreaks can save 10% to 25% of the cost of heating residential buildings. In this study, heating cost savings in widely scattered locations between 32° and 47° latitude ranged from 10% to 19% with windbreaks on the north and west. Also, although the windbreaks on the north and west were in near optimum locations, adjustments to their location might have resulted in savings that were even larger by a few percentage points.

Windbreaks also save some energy for cooling air conditioned buildings in warm climates, although in these simulations, savings were rather modest. Savings were 4% for a windbreak on the south in the warmest climate, (Wichita Falls, Texas). Air-conditioning savings would increase dramatically with shade trees close to the house (DeWalle, et al. 1983, Huang et al. 1990).

The results of this study illustrate the degree to which windbreak design recommendations should vary with climate and the range of savings that will result by varying design. For example, the windbreak on the south was much more effective in the Plains states than in Harrisburg. The difference between the effectiveness of the north plus west and the south windbreaks in reducing annual space conditioning costs was as much as 14.5 percentage points. If the south windbreak had been joined by one on the east, the difference between this combination and the windbreak on the north and west would still have been large.

The results reported here are in many respects tentative. For example, field measurements should be made to test both the assumptions regarding wind flow at the ends of windbreaks and the simulated irradiances on the building surfaces can lead to substantial errors in the estimated radiation reflected from the ground. In the simulations here, solar irradiances on building surfaces in winter were to some degree underestimated because the fraction of solar radiation reflected from the ground was assumed to be constant throughout the year rather than increasing with snow cover. In future work, this fraction could be varied as some function of estimated snow cover. Effects of windbreaks on air temperature might also be included. Utility rates were assumed to be uniform at all locations; rates could be varied to represent local conditions.

There is recent evidence that the algorithms within DOE 2.1 that model solar irradiances on building surfaces

A tall windbreak relatively close to a short house is a geometry that is relatively simple to model compared to other configurations, such as shorter windbreaks at the same distance. Nevertheless, these methods have potential for being of considerable aid in design of effective windbreak planting and management. For example, it would be possible to address such questions as whether, over the life of a windbreak planting, savings would be greater with a slower growing but dense conifer species or a faster growing but less dense deciduous species. Because of the many homes that could benefit from well designed windbreaks and the large amount of energy and dollars for heating and cooling them, even moderate improvements in windbreak design can be economically important.

ACKNOWLEDGEMENTS:

*Joe Huang, of Lawrence Berkeley Laboratory, provided valuable assistance in the use of DOE 2.1D. Stephen Gleason was responsible for computer operation and graphics. Joe Huang and David R. DeWalle provided helpful review comments.*

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## *Curriculum Vitae*

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