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The Principles of Using Woods for Shelter

INFORMATION NOTE

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SUMMARY

This Information Note describes the physical principles that determine the impact of woodlands on shelter provision. The importance of the woodland height, porosity, width, length, orientation and shape on the area and level of shelter are discussed. Three generic shelter wood types are identified ('windshield', 'windbreak' and 'hybrid') together with their most appropriate applications. The Note points to the crucial need to understand the reasons for creating shelter in order to determine the most effective shelter wood design and management.

INTRODUCTION

Throughout history humans have attempted to modify the climatic conditions affecting their crops and animals in order to increase productivity and comfort. In particular, trees have been planted in woods and belts to provide shelter and shade (Figure 1). Britain is one of the windiest countries in the world (Quine, 1995) so there is a long history of using trees for shelter in exposed parts of the British Isles. The agricultural improvers of the 18th and 19th centuries recognised the importance of shelterbelts in such a climate and we continue to benefit from their legacy (Mutch, 1997). Farmers still recognise the value of trees for shelter and the agricultural and forestry departments continue to encourage the establishment and management of farm woodlands for this objective (Forestry Commission, 2000). Recently there has been interest in encouraging the use of trees for the entrapment of air borne pollution (Forestry Commission, 1999) and to shelter urban areas to increase energy conservation (Patch, 1998).

Wind is the flow of air in response to atmospheric pressure differences and modifying this flow is the principal way in which shelter woods[1] are used to affect microclimatic conditions. Modifying the airflow not only affects wind speed but also **turbulence**[2] intensity, temperature, humidity and soil erosion. At the same time the shelter wood may affect the amount of sunlight falling on adjoining fields and heat loss due to radiation.

[1] The term 'shelter woods' is used in this Note to represent all woodlands that are valued for their shelter benefit. The term 'shelterbelt' is not used because it is usually identified with rectilinear plantations.
[2] Words in bold type are explained in Definitions (page 8).

Figure 1

Beech trees planted for shelter. Ayrshire, Scotland.

Shelter woods present a porous obstacle to approaching airflow creating an increase in pressure in front of the belt and a decrease behind. The high pressure slows the approaching flow down and forces it to be deflected upward (Figure 2a) in a region referred to as the **displacement zone** (Figure 2b). Above the top of the shelter wood the wind is accelerated and the increase in wind **shear** leads to an increased production of turbulence. Some of the approaching flow filters through the shelter wood with a reduced velocity (**bleed flow**) due to the drag provided by the trunks, branches and foliage. If the shelter wood is extremely dense then almost no air penetrates through the wood and a stagnant slow circulating **eddy** is formed behind the shelter wood (indicated by the **cavity zone** in Figure 2b). The more open the shelter wood the weaker this eddy becomes until it disappears completely and the **wake zone** begins immediately behind the shelter wood.

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Figure 2a The flow of wind over a shelter wood.

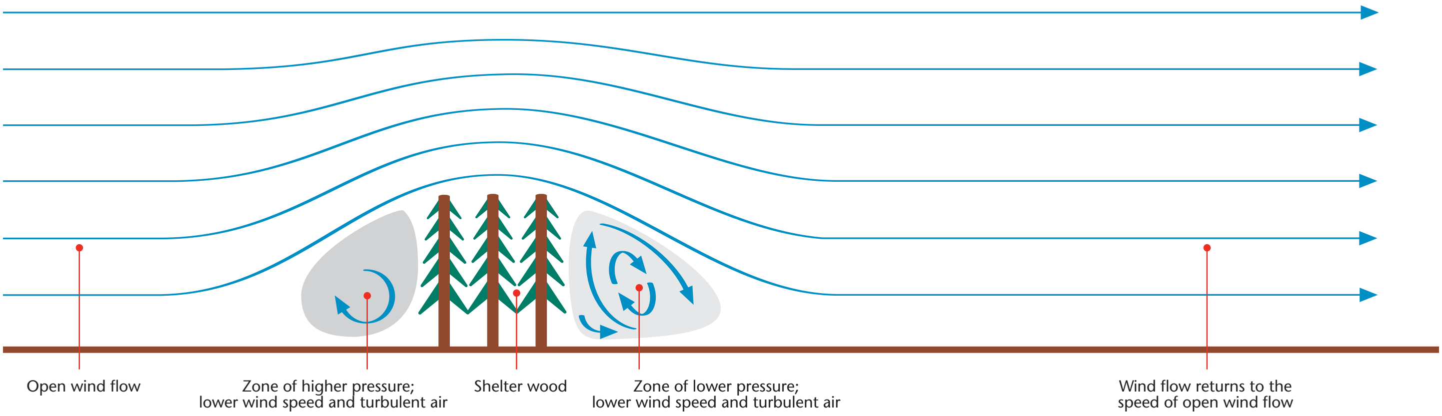
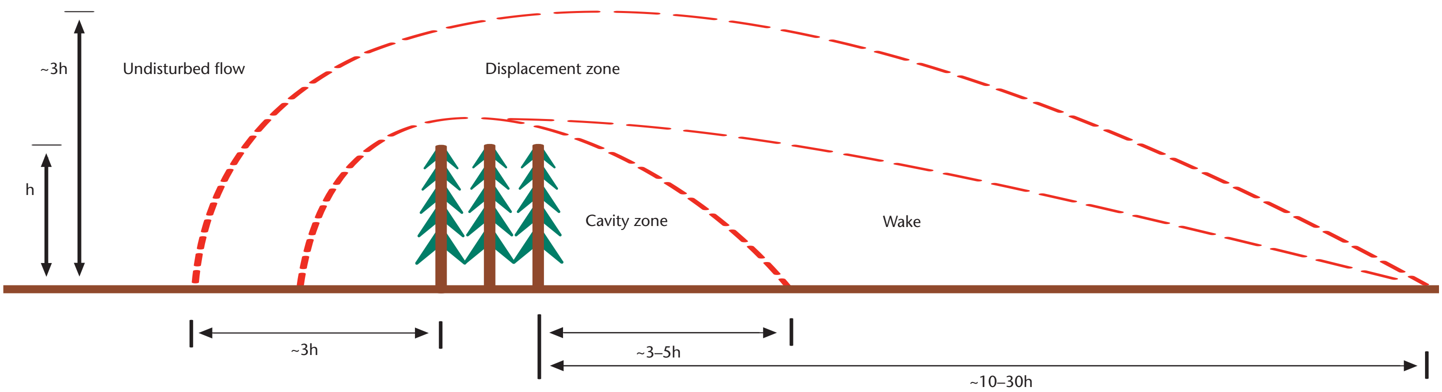


Figure 2b Wind flow zones created by the flow of wind over a shelter wood and their scale in relation to the height of the shelter wood.



The wake zone is the region in which fast moving air displaced above the shelter wood begins to mix with the slower moving air that has filtered through the shelter wood. Downstream of the shelter wood, within the wake zone, the wind speed gradually increases until it is the same as the wind speed upwind of the shelter wood. The wake zone is the main area where there are microclimatic benefits of shelter.

MICROCLIMATIC BENEFITS

A summary of the main microclimatic changes associated with shelter woods is given in Table 1.

The wind speed is reduced ahead of and behind the shelter. However, turbulence levels may be increased in the cavity zone, which can lead to increased **lodging** and abrasion damage to crops. Within the shelter wood itself the wind speed is generally reduced. However, if the wood has a very open understorey, squeezing of the flow between the canopy and the ground may increase the wind speed under the canopy.

The daytime temperature and humidity are generally increased in both the cavity and the wake zone. However, close to and within the shelter wood there may be shading from the sun, which will reduce the temperature. This may be a disadvantage if solar heating is important, but if crop scorching or sunburn to animals is a consideration it may be of benefit. Within the shelter wood the night-time temperature is raised because the canopy reduces **radiation transfer** to the atmosphere. However, the night-time temperature may be reduced in the cavity zone – if the belt is very dense – because it will restrict mixing of cold air near the ground with warmer air above. This could be important for animals sheltering behind or in dense belts on still clear nights.

Within the wake zone the reduced wind speed and turbulence leads to a reduction in the movement of gases to and from the ground. This means that moisture levels are higher and there is reduced water loss from the soil. Close to the shelter wood, within the cavity zone, this may lead to waterlogging if the soil is particularly wet, or increased plant growth if the soil is prone to drought. The reduced wind speeds can also lead to reduced soil erosion.

Table 1 Changes in microclimatic conditions in different areas adjacent to a shelter wood.

Area	Increased	Reduced
Displacement zone	• Wind speed above shelter wood • Turbulence	• Wind speed at ground level • Sunlight close to shelter wood
Inside shelter wood	• Wind speed (only for very open shelter wood) • Night-time temperature	• Wind speed (except for very open shelter woods) • Daytime temperature • Sunlight
Cavity zone	• Turbulence • Daytime temperature • Humidity • Lodging and abrasion • Waterlogging on wet soils	• Windspeed • Night-time temperature (on clear calm nights) • Sunlight close to shelter wood
Wake	• Daytime temperature • Humidity • Carbon dioxide	• Windspeed • Turbulence • Erosion • Water Loss

FACTORS CONTROLLING SHELTER WOOD PERFORMANCE

Height

The height of the shelter wood and the **porosity** are the most important factors controlling performance of a shelter wood. The area ahead of and behind the shelter wood over which it is effective is a direct function of shelter wood height as illustrated in Figures 3–5. The taller the shelter wood the larger the area of shelter.

Porosity

In simple terms, porosity (Definitions, page 8) is a measure of how open the shelter wood is and how easily the air can flow through it. The porosity of the shelter wood directly influences the intensity and area of shelter produced by the shelter wood. Porosity is affected by planting density, canopy distribution, species mix, shelter wood width and time of year.

Figure 3

The flow of wind across a dense shelter wood (0–40% porosity).

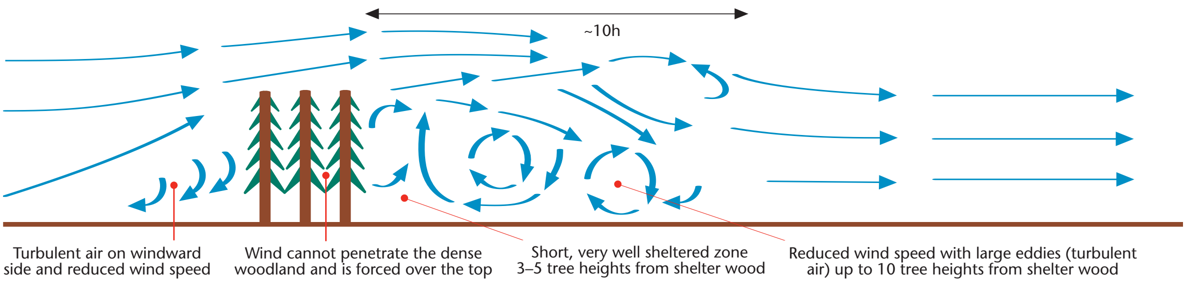


Figure 4

The flow of wind across a medium density shelter wood (40–60% porosity).

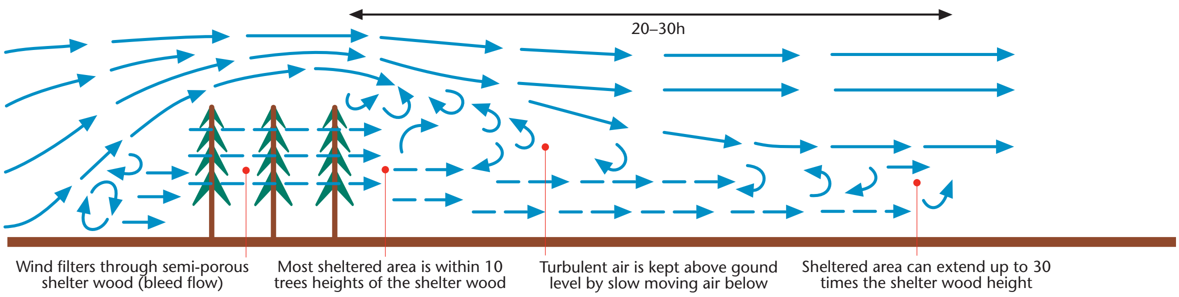
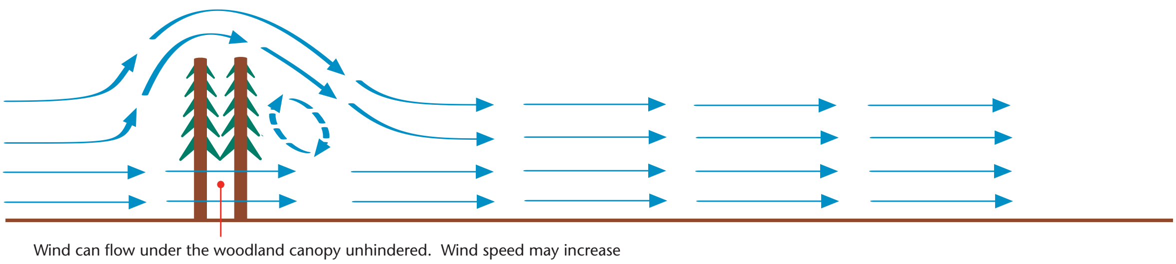


Figure 5

The flow of wind across an open shelter wood (60–100% porosity).



A dense shelter wood, or 'windshield' (Figures 3 and 6), will result from close spaced trees and shrubs, a large width of woodland or a combination of both factors. Shelter woods tend to have lower porosity when they are young and there are live branches down to the ground. The porosity tends to increase as the trees grow and the canopy lifts off the ground while, at the same time, self-thinning due to mortality will tend to lower the porosity as the shelter wood ages. The flow pattern across a dense shelter wood is illustrated in Figure 3. The majority of the air is forced over the trees by the high pressure ahead of the shelter wood. Because little air passes through the shelter wood, the flow separates and a cavity zone and a large drop in pressure is created behind the wood. This low pressure causes the high-speed wind above the shelter wood to return quickly to the surface giving a short region of shelter but with very reduced wind speeds.

A medium density shelter wood, or 'windbreak' (Figures 4 and 7) allows much more air to flow through the shelter wood. This reduces the chance of flow separation behind the wood so that the cavity zone may not exist and the wake zone begins immediately. The pressure changes across the shelter wood are also less severe than with the dense wood and, therefore, the return of the faster moving air towards the ground is more gradual. The result is the maximum area of shelter of any shelter wood but the intensity of the microclimatic changes are less dramatic. Figure 8 shows a 'hybrid' shelter wood with a medium density upper storey and dense lower storey. A broadleaved shelter wood such as this may have a high porosity in the winter but a much lower porosity in the summer (compare Figures 8a and 8b).

An open shelter wood (Figures 5 and 9) has a limited area of shelter and the reduction in wind speed downwind may be minimal. If the lower part of the shelter wood canopy is completely open, it is possible to increase the wind speeds within and just downwind of the wood compared with the open field values.

Figure 6

Dense shelter wood ('windshield').

Figure 7

Medium density shelter wood ('windbreak').

Figure 8

A medium density upper storey, dense lower storey shelter wood ('hybrid') in (a) winter and (b) summer.

Figure 9

Open shelter wood.

Width

Width is generally not of such direct importance as height except in the way it affects porosity. A two-row shelter wood is as effective as a six-row shelter wood, provided they both have the same porosity, and it takes up less land. In extremely windy climates the leading rows of trees may be stunted in their growth and, therefore, a wider shelter wood will be necessary to obtain the required height.

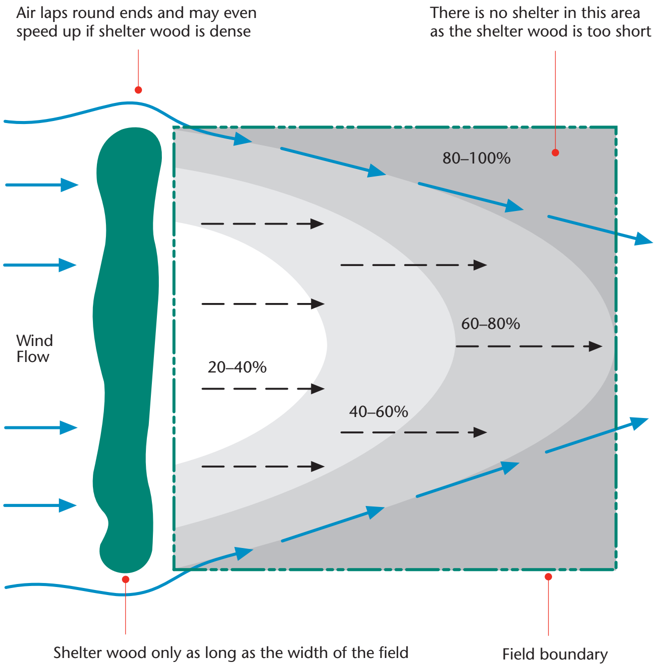
Very wide shelter woods (width >2 x tree heights) do not provide more shelter than a narrow belt because they behave very similarly to a dense shelter wood and wind speeds recover very quickly in their lee. Furthermore, the turbulence intensity over wide shelter woods is more developed and can lead to problems of lodging and plant abrasion.

Length

The shelter wood must be longer than the length of the area requiring shelter. This is due to the triangular shape of the sheltered zone (Figure 10). The air speeds up around the edge of the shelter wood resulting in higher wind speeds and turbulence levels in this area. Behind the shelter wood this high-speed turbulent air begins to encroach into the sheltered wake zone in an identical manner to the air that was displaced over the shelter wood.

Figure 10

The effect of shelter wood length on the area of land afforded shelter and the degree of shelter. The values shown (e.g. 20–40%) give the wind speeds expected for a particular area as a percentage of the open field value (unsheltered).



Orientation

The orientation of the shelter wood to the wind affects the area provided with shelter. The greatest area of protection is provided when the wind strikes the shelter at right angles but this is reduced when the wind strikes at a smaller angle (Figure 11). Therefore, the shelter wood is ideally located when it lies across the wind direction of particular concern. However, it is possible to construct shelter woods that provide protection from more than one direction (Figure 12).

Orientation also has an effect on porosity. The shelter wood is most porous to the wind when the wind strikes it at right angles. As the angle is reduced the porosity decreases because the effective width of the shelter wood is increased. The effect is more marked with wide shelter woods.

Figure 11

The effect of shelter wood orientation to the direction of wind flow on the area of land afforded shelter.

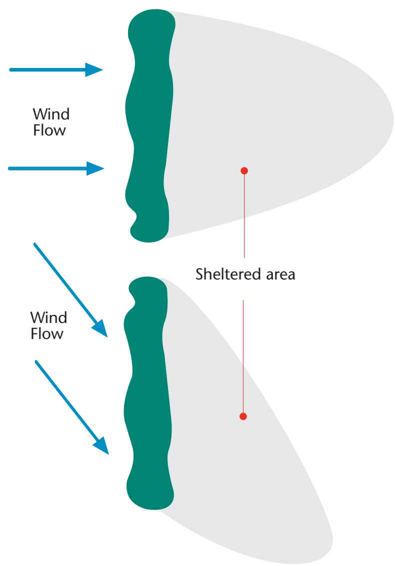
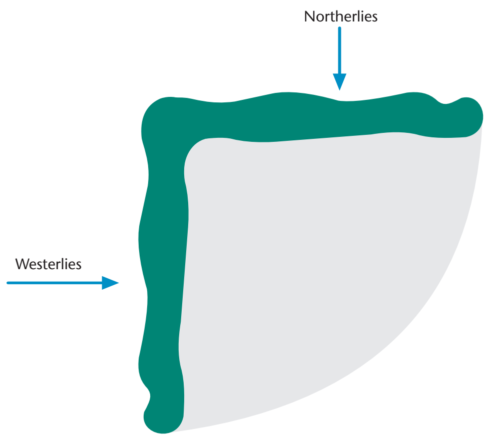


Figure 12

A shelter wood designed to be effective for two wind directions.

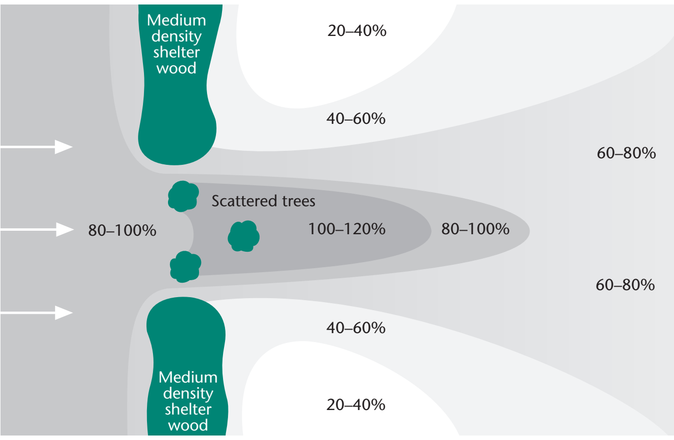


Openings

Any opening in a shelter wood has the same effect as the end of the shelter wood by increasing the wind speed and turbulence through the gap (Figure 13). The wind speeds within the opening may be significantly higher than the up-wind values. If an opening is required for access then it should be angled through the shelter wood or a 'dog-leg' included.

Figure 13

The effect of an opening in a shelter wood on wind speeds. The values shown give the wind speeds expected for a particular area as a percentage of the open field value (unsheltered).



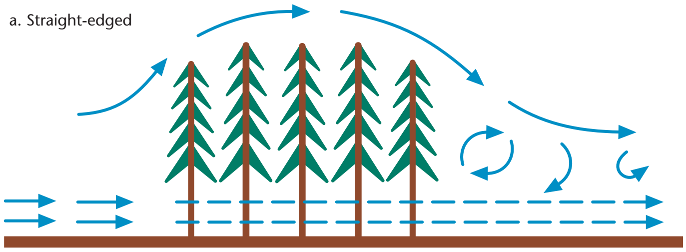
Shape

The ideal profile for a shelter wood is generally straight sided. This provides the maximum shelter for the minimum use of ground (Figure 14a). A profiled edge will tend to deflect more air over the shelter wood and allow less air to flow through the trees (Figure 14b). The result is to produce a sheltered area very similar to that achieved with a dense shelter wood.

Figure 14

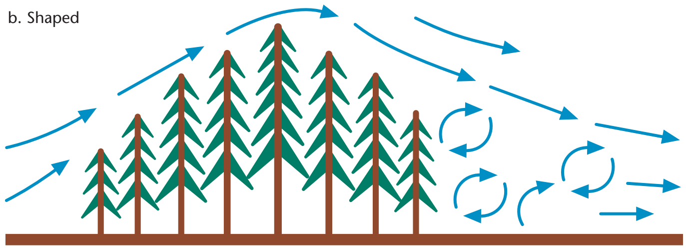
The effect of the shape of a shelter wood profile on wind flow.

a. Straight-edged



A staight windward edge encourages air to filter through trees, increasing length of sheltered zone and reducing risk of turbulence

b. Shaped



A-shaped profiles lead to little filtering of air through trees, shorter sheltered zones and increased risk of turbulence

TYPES OF SHELTER WOOD

Differences in the porosity of the shelter wood produce different intensities and areas of shelter. By adjusting the porosity of the shelter wood and the vertical distribution of canopy elements different forms of shelter wood can be produced, which are appropriate to different shelter applications. Porosity can be increased by thinning, pruning and reducing shelter wood width. Porosity can be decreased by underplanting, increasing the width of the shelter wood or, for example, by the use of fencing, hedging and straw bales. In Table 2 the three basic types of shelter wood are set out with a description of the area and intensity of the shelter zone and their most appropriate applications.

Table 2 Descriptions of shelter wood types, their impact on wind speeds and their application.

Shelter wood type	Broad description of features (porosity/height/length)	Porosity profile	Length of wind speed reduction	Reduction of open wind speed	General application
Windshield (Figure 3 and 6)	• dense • as tall as necessary • as long as necessary	<40%	Up to 10 x height of the wood (max. shelter at 3–5 times the height)	up to 90%	• lambing/calving areas • feeding areas • farm buildings
Windbreak (Figure 4 and 7)	• medium density • as tall as possible • as long as necessary	40–60%	20–30 x height of the wood	20–70%	• crops • improved pasture
Hybrid (Figure 8 and 15)	• dense lower storey; medium density upper storey • as tall as possible • as long as necessary	<40% lower storey	5 x height (approx) of the lower storey	up to 90%	• where a combination of applications suit both windbreak and windshield shelter wood types
		40–60% upper storey	20–30 x height of the upper storey	20–70%	

SUMMARY

- The denser the shelter wood the greater the reduction in wind speed, the shorter the sheltered zone and the greater the turbulence in the lee.
- The taller the shelter wood the larger the area of shelter for any density of shelter wood.
- Porosity is more important than width – a narrow shelter wood with equal porosity to a wide shelter wood will be equally effective.
- The area of shelter behind a shelter wood is roughly triangular with the base set by the length of the shelter wood.
- Wind speeds are increased at the end of shelter woods and within any gaps or openings through the shelter wood.
- Shelter woods that are straight sided will be more effective than those with a tapered profile.
- Very wide shelter woods tend to have low porosity and provide a limited area of shelter.
- Dense (0–40% porosity) shelter woods create small but very sheltered zones appropriate for lambing, calving and feeding and the protection of buildings (Figures 3 and 6).
- Tall semi-permeable (40–60% porosity) shelter woods provide effective shelter to the largest area and are most appropriate for sheltering arable crops and grazing animals (Figures 4 and 7).
- Hybrid shelter woods with low porosity at their base and higher porosity at their top can provide a dual shelter function with a relatively wide area of shelter and an intense area of shelter close to the shelter wood (Figures 7 and 10).
- Very open (> 60% porosity) shelter woods are of little value and can actually increase wind speeds locally.
- Understanding the reasons for creating shelter will determine the most effective shelter wood design and management.

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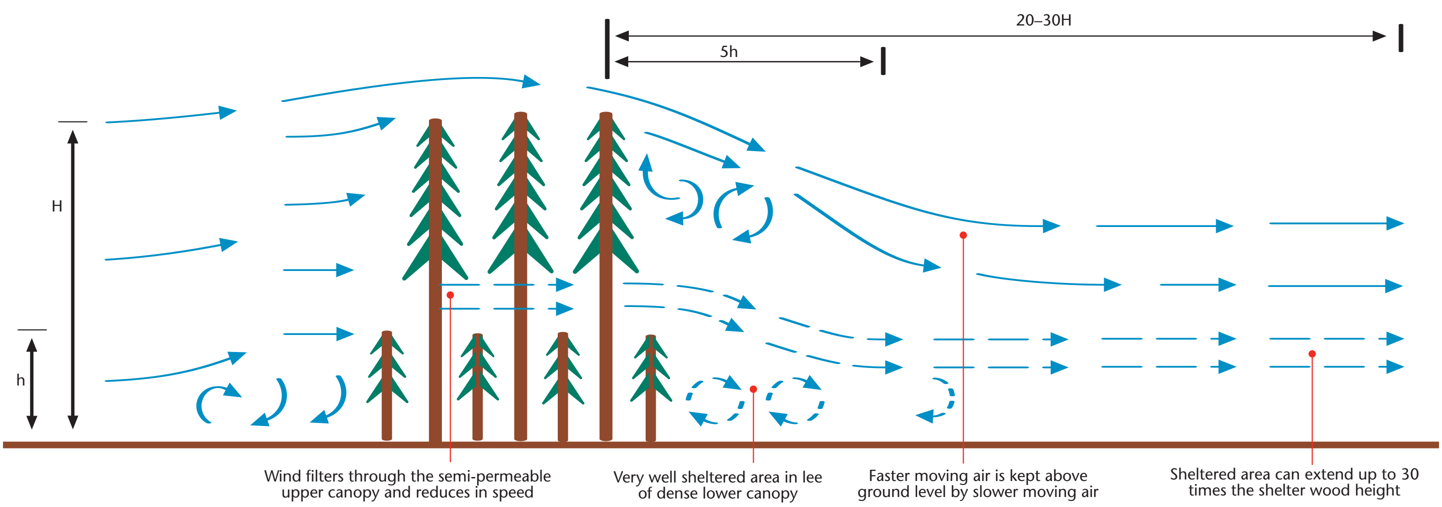
Figure 15 The flow of wind across a 'hybrid' shelter wood (Upper storey 40–60% porosity, lower storey < 40% porosity).



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Further information

This Information Note on The Principles of Using Woods for Shelter will be supported by additional information about the role of woods for shelter. Topics will include:

- Designing shelter plantings
- Farm woodland shelter assessment
- Protecting grazing livestock
- Protecting newly born lambs and calves
- Protecting crops and grassland

For more information, visit: www.forestry.gov.uk/shelter

Definitions

Bleed flow
The flow which filters through the shelter wood.

Cavity zone
A region of recirculating very low velocity air behind a shelter wood. Exists when the porosity is low and is absent when the porosity is above 40%.

Displacement zone
The area ahead of and above the shelter wood in which the flow is displaced upwards.

Eddy
A circular motion in the airflow.

Lodging
Wind damage to crops either by uprooting or by stem/stalk breakage. Exacerbated by turbulence.

Porosity
A measure of the ease with which air may move through a shelter wood. Optical porosity is a rough guide to the aerodynamic porosity and is the ratio of sky visible through the shelter wood to the area occupied by the shelter wood. An optical porosity of 0% represents a very impermeable shelter wood which cannot be seen through, a porosity of 90% would represent an extremely open shelter wood.

Radiation transfer
The radiative exchange of energy with another body or the atmosphere. During the day radiation transfer from the sun heats up the ground, plant canopies and animals. During the night radiation transfer to the sky cools the ground, canopies and animals. The cooling is most rapid when the sky is clear.

Shear
Any change of wind velocity with a change of position. Strong vertical shear exists over a shelter wood and strong horizontal shear exists at the end of shelter woods. Shear produces turbulence.

Turbulence
Random motions in the air. Turbulence encourages the exchange of gases between the atmosphere and plants, and heat between the atmosphere and animals and plants. High turbulence can lead to lodging and abrasion.

Wake zone
The main area of shelter behind a shelter wood. This is the region in which faster moving air displaced above the trees begins to mix back towards the ground.

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