#3661

LIGHT ATTENUATION BY TREES

G T McKennan
Department of Architecture and Landscape
Manchester Polytechnic

For Presentation at the Building Research Establishment

Seminar: "Microclimate and the Environmental Performance of Buildings"

April 1988

1. Introduction

The use of daylight to offset the consumption of electricity for lighting within buildings has become a recognised building energy management concept (1) Trees by their very nature attenuate light from the sky and are therefore potentially in conflict with this natural lighting of building interiors.

The customary means of expressing interior daylighting is by the 'daylight factor', the internal illuminance expressed as a percentage of illuminance occurring simultaneously on a horizontal surface outdoors exposed to the whole overcast sky. The daylight factor at a point in a room depends largely on the area of sky that can be seen through the window from that point (Fig. 1) Both tree geometry and crown attenuation characteristics are therefore important in predicting the reduction in daylight in an interior due to the presence of trees. This would not present a problem for the designer if trees were simply obstructional features of the landscape. However, they have many positive roles to play around buildings. People prefer views of trees, grass and open space to views of adjacent buildings. Trees have positive associations within our culture and language. They can attenuate noise and can act to improve the energy efficiency of buildings by performing as wind breaks and by providing solar shade in summer.

Careful consideration of their light attenuation characteristics is therefore necessary before we judge them as desirable or not within our designs.

2. Measurement

Measurement of the light attenuation characteristics of trees is not immediately straightforward. The literature shows a variety of measurement quantities and techniques being used by other authors. A review of these is contained elsewhere (2).

For daylighting design, the accepted conditions in the UK are still those known as the CIE standard overcast sky (3). A densely overcast sky with a known luminance distribution. Figure 2 shows for these conditions the possible pathways by which diffuse daylight radiation might reach a measuring point. We can identify six such possible pathways.

The most significant of these pathways is that described by the admission of light through gaps in the tree crown (pathway A). The openness or constriction of these gaps due to seasonal or species differences is the major cause of variation between measurements. It is this which allows a simplified method of estimating attenuation due to existing trees (2).

Of secondary importance is the pathway described by light reflected from the surface of the tree crown (pathway B). Although reflectance is low for bare branches, this pathway can be significant for trees in leaf. Investigations of forest canopies have suggested this could be 15%-20% (34).

Light can also reach the measurement point by internal reflection within the tree crown itself (pathway C). This is likely to be neglgible towards the centre of the crown due to the high proportion of light absorbed in the multiple interreflections between branches or leaves. But it may be significant toward the edge of the crown where the number of interreflections is reduced. This may partly account for previously noted edge effects (5).

Similarly, for a tree in the foliate state, a small amount of light can reach the measurement point being transmitted through the leaves themselves (pathway D). A value of 3.9% (6) for each leaf has been suggested for Horse Chestnut (Aesculus hippocastanum). Where multiple transmissions occur, light reaching the measurement point by this pathway is likely to be negligible.

Figure 2 shows that light can reach the measurement point by two other pathways which do not involve the tree itself. Firstly, light may reach the measurement point directly from the unobstructed sky (pathway E).

Secondly, though generally of less significance, light may reach the measurement point from other external objects (pathway F) such as buildings or other trees by either reflection or transmission. In order to arrive at an accurate measurement of diffuse light attenuation of a tree crown, light reaching the measurement point via both these pathways needs to be discounted.

To arrive at a measure of attenuation discounting these two pathways one would ideally use a directional photometer that sampled the whole tree crown alone and one would simultaneously sample the patch of sky occluded by the tree crown, expressing the luminous intensity of the former as a proportion of the luminous intensity of the latter.

As an approximation to this we adopted a method illustrated by Figure 3, whereby discreet luminance measurements were made in rows across the crown and of the sky immediately on either side. To minimise any error due to sky luminance mesurements not being taken simultaneously with crown luminance measurements, values were recorded verbally onto audio tape and transcribed later. Each measurement of sky luminance was taken as representative of sky luminance for its continguous half row of measurements within the boundary of the tree crown. Figure 3 shows how the set of luminance measurements were then expressed as percentages and then as a single average value. To reduce any error due to the choice of sampling points within the boundary of the crown, the above procedure was performed five times for each tree and a final average determined.

This average value arrived at represents attenuation of the tree crown for a given angle of elevation. Figure 4 shows changes of attenuation with angle of elevation recorded for a single tree. Figure 5 illustrates diagrammatically that this may be due to differences in path lengths. If these recorded changes are due to differences in path length then changes in attenuation will be different between species due to their differences in crown geometry. This still awaits systematic study.

3. Some Preliminary Results

Using the method described above, a sample of forty-two trees covering seven species was surveyed (7). The seven species, chosen for their common occurrance in Britain were Ash (Fraxinus excelsior), Beech (Fagus sylvatica), Horse Chestnut (Aesculus hippocastanum) Small-leaved Lime (Tilia cordata), Penduculate Oak (Quercus robur), Silver Birch (Betula pendula) and Sycamore (Acer pseudoplatanus).

Three phases of the annual cycle of growth were studied. They were winter, leaf formation and summer. Some results from these are discussed below:

3.1 Winter

The results of this first phase are summarised in Figure 6, where means of attenuation are shown for each species. Ash was found to have the lowest attenuation at 34% whilst Beech had the highest at 52%. For a point in a building interior from which sky can only be seen through a tree canopy, these figures approximate attenuation of the potential daylight factor at that point.

The difference in attenuation between Ash and Beech is a difference of 18% but it is likely that this does not represent the maximum difference between UK species. The inclusion of other UK species would probably extend this range.

The reliability of these single values for attenuation in predicting the actual attenuation by an individual tree depends on the species chosen. Table 1 shows data allowing us to compare the most reliable (Horse Chestnut) with the least reliable (Beech). Both species show similar standard deviations between measurements of individual trees, but the standard deviation between trees differs from 1.576 for Horse Chestnut to 5.148 for Beech. A single value for attenuation is therefore likely to be more reliable a predictor for Horse Chestnut than for Beech.

3.2 Leaf Formation

In order to record changes in the attenuation characteristics of the seven species of tree selected during the leaf formation period it was necessary to take measurements on a more frequent basis than during winter. It was therefore necessary to reduce both the number of trees within each species and the number of sets of measurements of each tree. One set of measurements was made of three trees for each species each fortnight for two and a half months until the trees appeared by visual inspection to have finished leaf formation. It was felt that this would be sufficient to reveal any characteristic development patterns in changes of attenuation.

Figure 7 shows the results for two species (Lime and Ash) as examples of the data. The data for Lime clearly show consitancy between individual trees, suggesting that for this species a single value could be a reliable index. Ash shows greater variation, but even here a characteristic shape distinct from that of Lime is evident. The data for Ash also suggests that although individual trees within the species may have different attenuation levels, the proportional change from winter to summer may be consistant within the species. There is also a suggestion that when individual trees start their leaf formation relatively late they then proceed to change more rapidly. This was noted in other species and has been observed elsewhere (8).

3.3 Summer

The summer crown survey was carried out using the same forty-two trees and the same survey method as for the winter crown survey. Figure 8 illustrates the results of this survey showing mean values of attenuation for the seven species. The range in attenuation is almost as large as for the winter state, with a 15% difference between Ash with the lowest attenuation at 76% and Lime with the highest at 91%. However, the rank order of the species changes, for example Silver Birch becomes second lowest instead of third highest attenuator. This change in rank order between winter and summer is consistant with results from North American species (9).

In order to take measurements of the forty two trees in full leaf, the assumption had to be made that over the period of measurement, no significant changes in crown characteristics took place. Although there were no visible changes taking place, measurements were taken of two single trees, a Beech (chosen because it had been used for a similar check in winter) and a Silver Birch (chosen because of its gradual development during leaf formation). Whilst the Beech exhibited no consistant change with time, the Silver Birch increased attenuation by about 6% between July and August. The slow change in attenuation of Silver Birch over the leaf formation phase suggested that this species was the most likely of our chosen species to continue changing.

4. Conclusions

The small sample of trees used in this survey necessitates that we treat any results with caution. Nevertheless, it is worth making some tentative conclusions.

There do appear to be clearly defined differences in diffuse light attenuation characteristics of British tree species. It seems possible with some degree of reliability to rank order species accoring to their level of attenuation for both winter and summer. This is perhaps the most immediately useful conclusion. Figures 6 and 8 could therefore be used to aid tree selection. For example, in areas where summer shading is necessary, Lime would appear to be a good choice as it has the highest attenuation level in summer whilst having an average attenuation level in winter. Where minimising attenuation (maximising daylight) is required, Ash would be the most appropriate choice as it has the lowest attenuation both winter and summer. Furthermore, it is very late in beginning to develop its leaves as suggested in Figure 7.

Single figure attenuation levels as given in Figures 6 and 8 are useful but they are also deceptive. They suggest a static state which would appear to be far from the truth. We can hypothesise that the values given for winter are reiable because by their nature trees are dormant during this period. However, this is followed by a period of leaf formation extending to almost three months in which attenuation is changing significantly. The summer period may appear static, but for some species measurements suggest this is not so. Summer is then followed by a period of leaf fall in which attenuation will necessarily change. We can speculate from observations that this may extend and over a shorter period than leaf formation but it awaits systematic study. For some species, a simple winter/summer dichotomy may well prove inadequate.

REFERENCES

1. Crisp V H C, Littlefair P — Daylighting as a Passive Solar Energy Option BRE/CR12/87 May 1987

   Cooper I and McKennan

2. Yates D — Light Attenuation Characteristics of Trees RR/87/1 Department of Architecture and Landscape Manchester Polytechnic 1987

3. Commission Internationale de l'Eclairage Compte Rendu, Sect. 3.2, Al, 1955

4. Reifsnyder W E and Lull H W — Radiant Energy in Relation to Forests Technical Bulletin No 1344, US Dept. of Agriculture Forest Service 1965.

5. Wagar J A and Heisler G M — Rating Winter Crown density of deciduous trees - a photographic procedure. Landscape Journal 9-18, 5 1986

6. Ford E D and Newbold P J — The Leaf Canopy of a Coppiced Deciduous Woodland, Journal of Ecology 843-862, 59, 1971

7. Yates D — Light Attenuation Characteristics of Trees RR/87/2 Department of Architecture and Landscape, Manchester Polytechnic 1987.

8. Halveson H G Gleeson S B and Heisler G M — Leaf Duration and the Sequence of Leaf Development and Abscission in North Eastern Urban Hardwood Trees, Urban Ecology 323-335, 9, 1986.

9. Gardner T J and Sydnor T D — Interception of Summer and Winter Insolation by Five Shade Tree Species. Journal of the American Society for Horticulture 445-450, 109, 1984.

BEECH I	19.2.87- 17.3.87	43.87	45.54	40.99	48.87	38.68	38.80	42.79 (2)	3.689
BEECH II	4.3.87- 17.3.87	49.64	[illegible].26	45.93	44.93	42.20	44.00	45.16 (3)	2.296
BEECH III	26.3.87.	41.65	44.75	36.27	42.54	42.58	-	41.56 (1)	2.834
BEECH IV	26.3.87.	53.03	51.06	54.31	57.66	51.55	-	53.52 (5)	2.364
BEECH V	26.3.87.	53.06	56.05	53.83	56.83	54.72	-	54.90 (6)	1.386
BEECH VI	26.3.87.	53.83	54.29	46.79	47.17	48.22	-	50.06 (4)	3.303
								48.00	5.148
HORSE CHESTNUT I	3.3.87.- 25.3.87.	56.40	56.61	63.10	57.74	57.75	60.56	58.69 (3)	2.391
HORSE CHESTNUT II	4.3.87.- 25.3.87.	52.53	54.37	57.57	52.45	59.69	52.78	54.90 (1)	2.783
HORSE CHESTNUT III	4.3.87.& 31.3.87.	60.58	57.78	57.62	59.60	61.45	-	59.41 (5)	1.512
HORSE CHESTNUT IV	31.3.87.	57.38	55.61	59.48	61.84	61.14	-	59.09 (4)	2.322
HORSE CHESTNUT V	31.3.87.	55.23	58.06	61.60	60.41	61.91	-	59.44 (6)	2.503
HORSE CHESTNUT VI	30.3.87.	60.29	60.81	58.67	52.28	-	-	58.01 (2)	3.402
								58.26	1.576

Table 1 Diffuse light transmittance plus reflectance for Beech and Horse Chestnut in the winter crown phase.

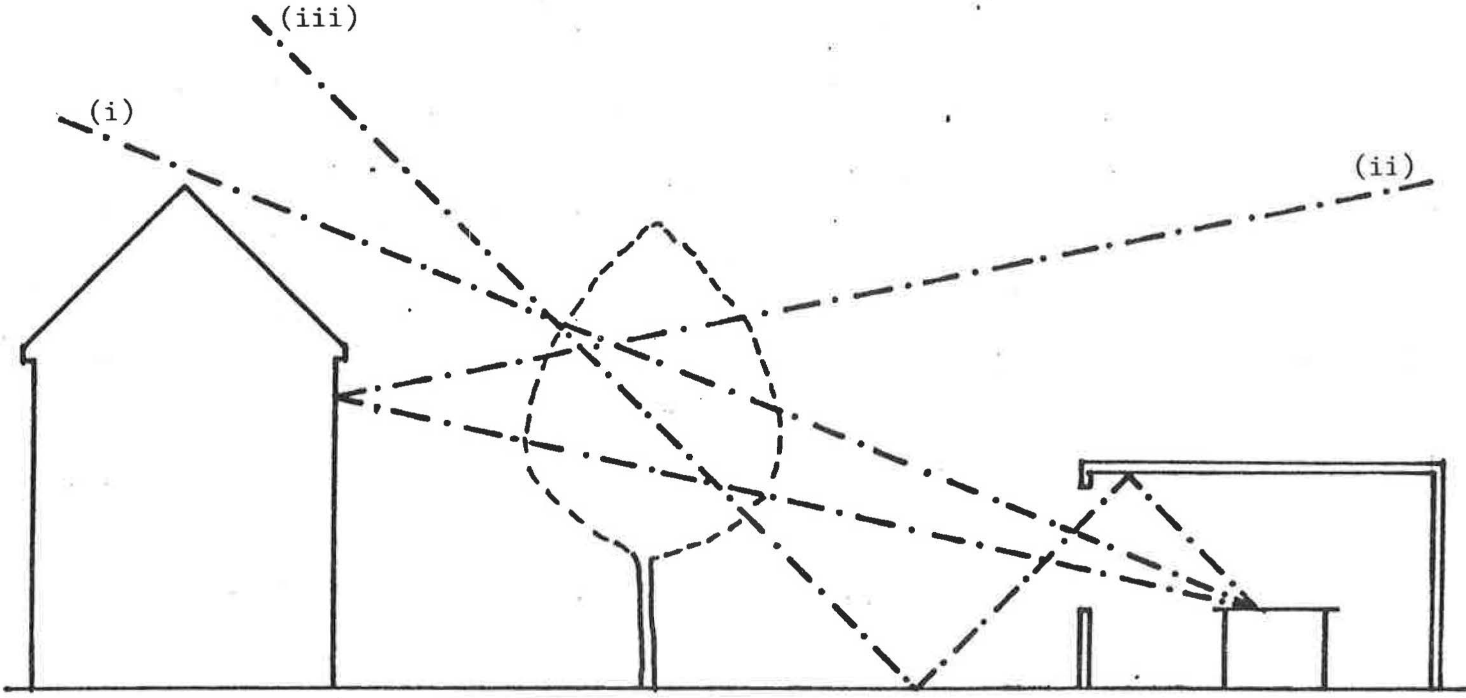

Figure 1. The three components of the daylight factor (i) sky component (ii) externally reflected component (iii) internally reflected component. All three components can be reduced by the presence of a tree.

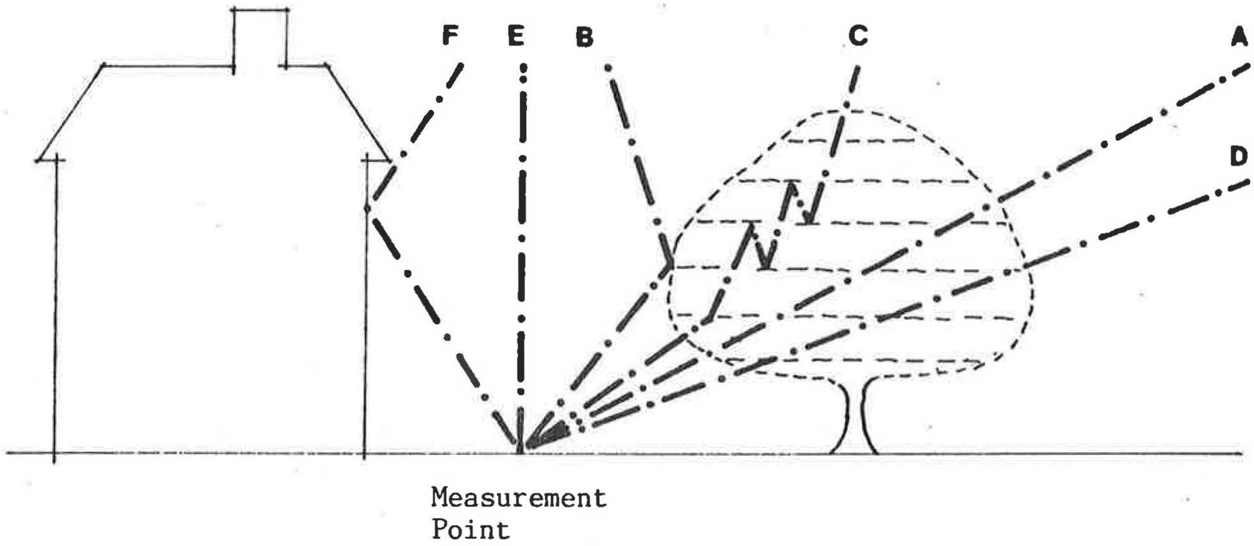

Figure 2. Possible pathways by which diffuse radiation can reach a measurement point.

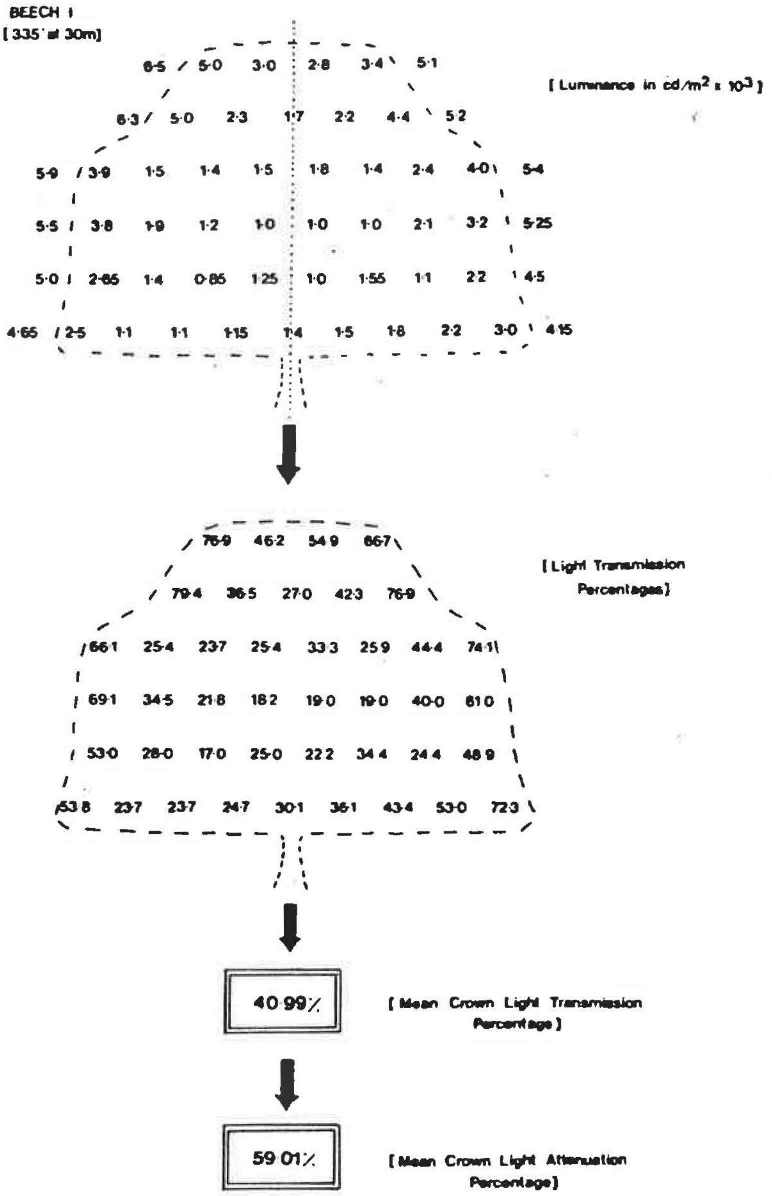

Figure 3. An example of the transformation of a set of measurements of luminous intensity into mean attenuation percentage.

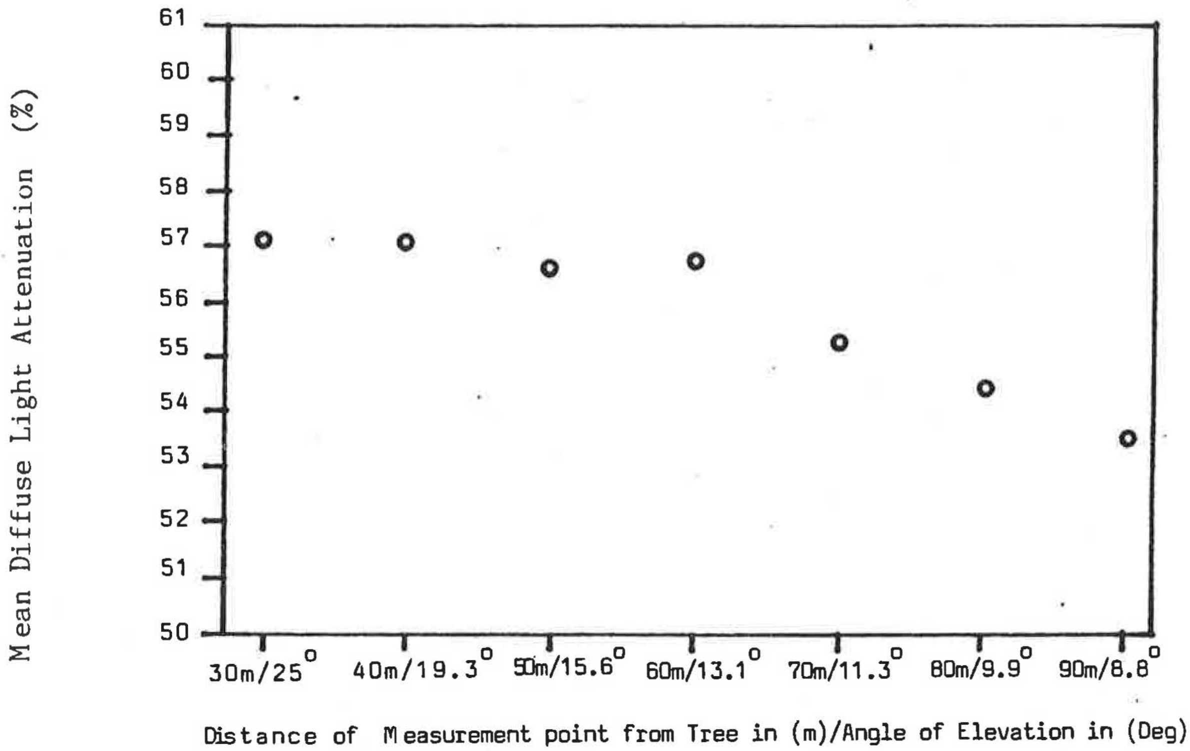

Figure 4. Graph showing the effect of the distance of the measurement point from the tree (thus angle of elevation of the tree) on diffuse light attenuation.

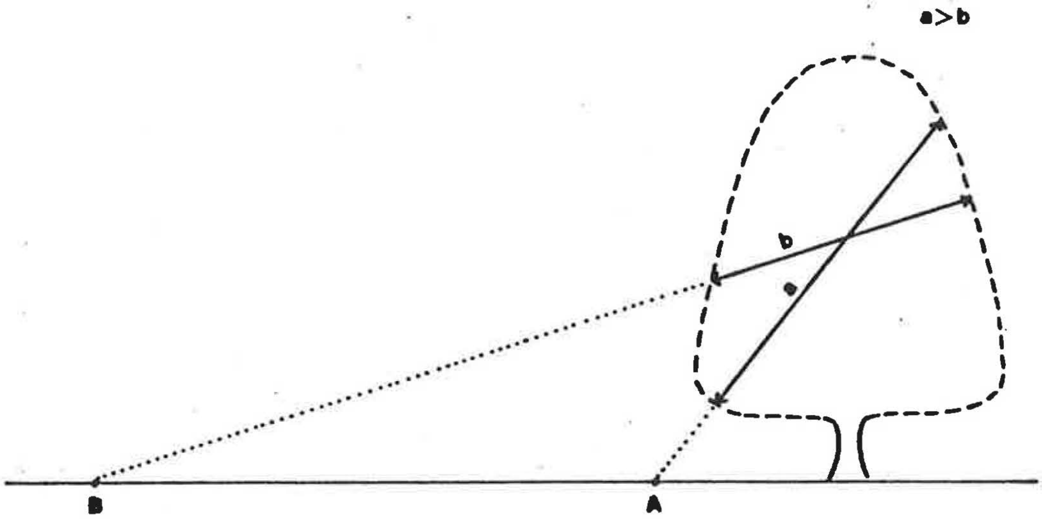

Figure 5. Diagram showing how the path length of solar radiation through a tree crown can be affected by angle of elevation. Light reaching point A has to travel further through the crown than that reaching point B.

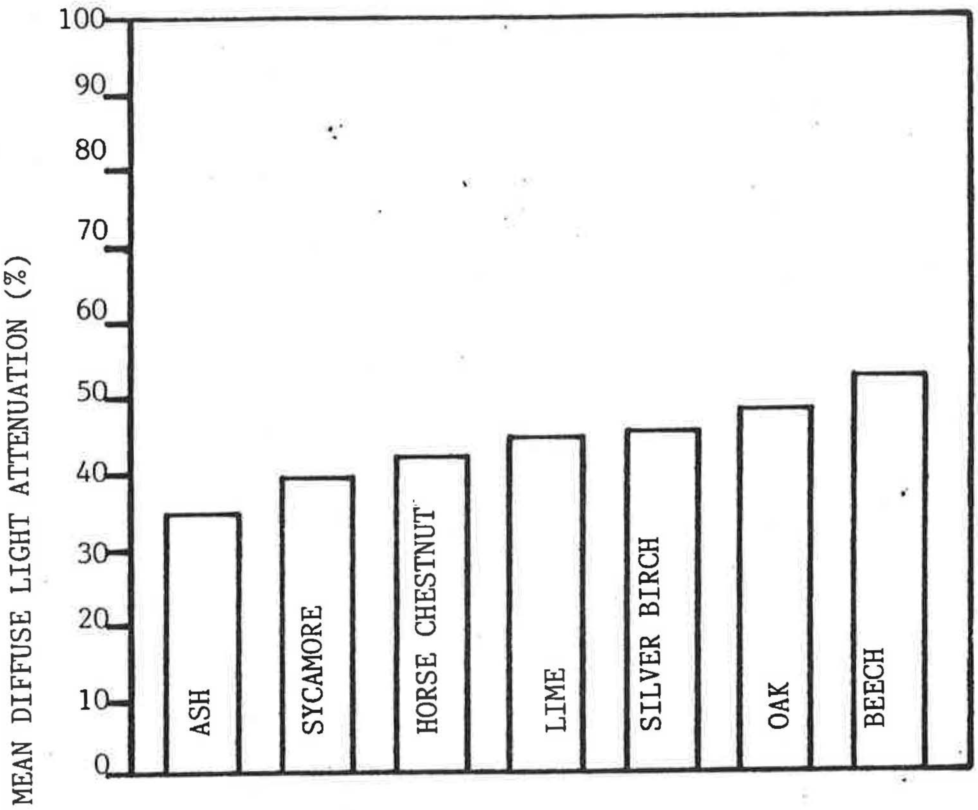

Figure 6. Mean diffuse light attenuation percentages for each of the seven species of tree in the winter crown phase.

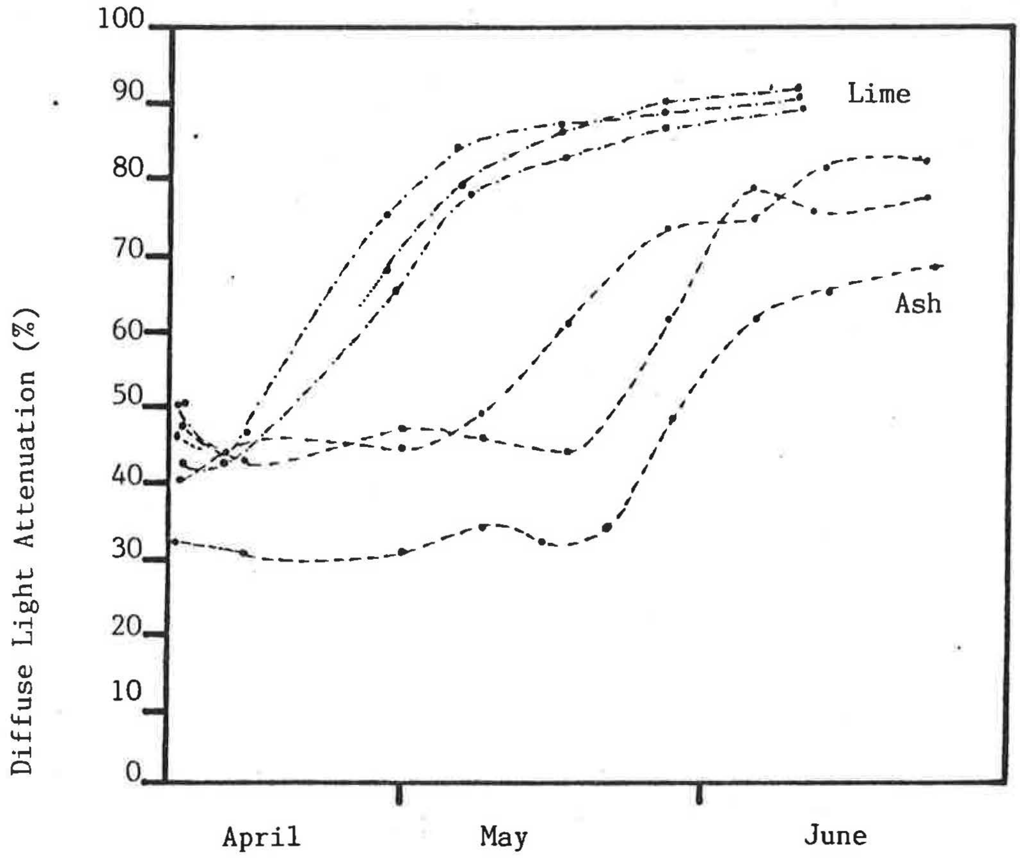

Figure 7. The change in diffuse light attenuation over time during the leaf formation period for Lime and Ash.

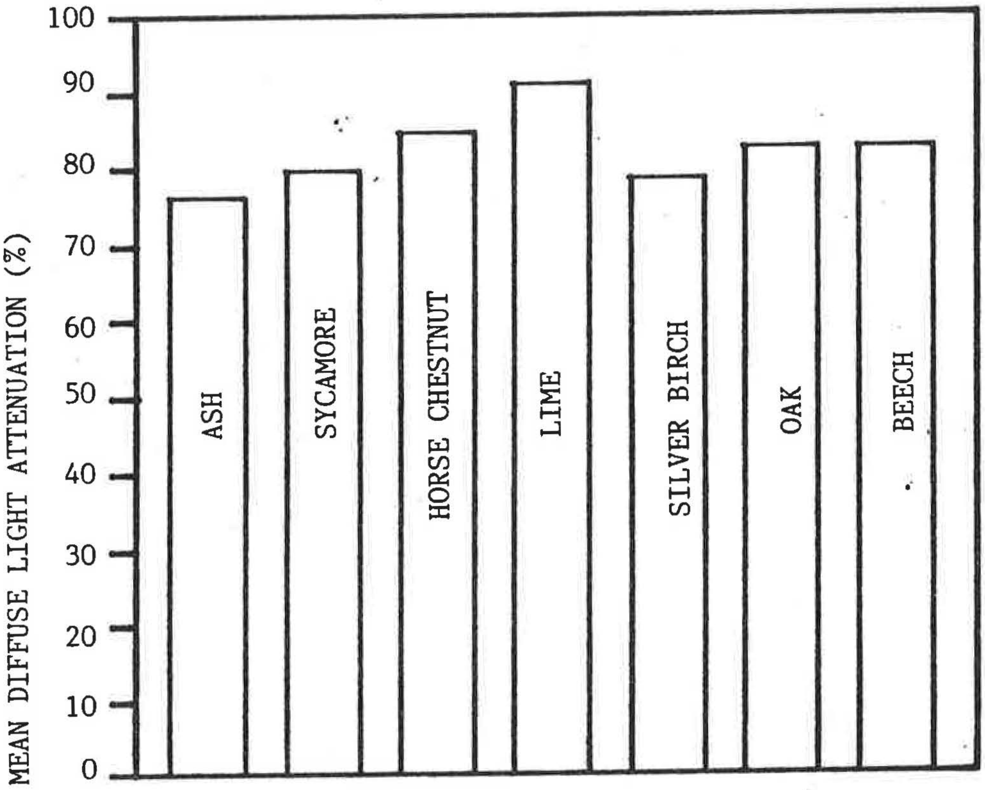

Figure 8. Mean diffuse light attenuation percentages for each of the seven species of tree in the summer crown phase.