URBAN FOREST ACOUSTICS

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ABSTRACT

Trees and plants in general can attenuate the sound by reflecting, refracting and absorbing energy. Certain types of vegetation are better attenuating sound than others. Sound transmission with trees, tree belts and forest stands is expressed as excess attenuation. From acoustical point of view, the relevant characteristics of a forest are: tree species, trunk diameter, number of trees/unit area, scattering and absorbing cross section, leaf area, the bark, the canopy, and of the forest floor. An acoustic wave of 1 kHz frequency propagates with a wavelength comparable with the trunk diameter.

The trunk, the branches and the foliage scatter partially the incident acoustic energy. The sound scattering by belt of vegetation and barriers is largely used for reducing traffic noise by reflection and absorption. The skilful design of barriers is an outstanding example of acoustic ecology, encouraging a deeper appreciation for noise and its role in our lives.

1. Introduction

The concept of urban forestry has been developed firstly in Canada, during the years 1960 and was defined as a practice proposing a global approach of tree management in view of integration of urban activity and population. In urban areas, trees are labelled urban trees in contrast with forest trees.

The existing information in the literature on noise reduction in urban environment with belt of trees is disseminated in publications related to forest and agricultural studies are quite abundant during the period 1970 -1990. Later, the subject was quite abandoned by forestry literature, and, during the last twenty years acoustical publications put stress on noise propagation modelling techniques in forest (Bucur 2005).

The aim of this article is to demonstrate the effectiveness of noise abatement with trees in urban areas.

2. PHYSICAL ASPECTS OF NOISE ATTENUATION BY URBAN FOREST

Figure 1 synthesised the factors effecting the noise attenuation in a forest stand through absorption, dispersion, reflection and refraction. Noise attenuation in its totality is composed of normal attenuation and excess attenuation. Normal attenuation is due to spherical divergence and air absorption (Embelton 1996). Furthermore, reflection, refraction, scattering and absorption effects due to any obstruction (barriers, ground, vegetation, trees, hills, etc) between noise source and receiver results in excess attenuation (Fang and Ling 2003). The main dendrological and physical characteristics of the stand effecting excess attenuation in a tree belt are shown in Fig. 2. These characteristics are: the biomass of the stand, the structure of the stand in horizontal plane, (the size and the shape of the canopy), the quality of the surfaces (size and shape of leaves and needles, soil). These parameters allow admitting that mixed stands composed from coniferous and deciduous trees and bushes would be the most effective for noise attenuation.

A simple calculation of the wavelength of a sound wave of 1000 Hz frequency interfering with trees in a forest shows that the wavelength is comparable with trees diameters. The incident acoustic waves are partially reflected and refracted producing a typical scattering phenomenon as shown in Fig 3. The branches and the foliage scatter partially the incident acoustic energy to the side and backwards, producing a shadow zone behind the vegetation. The canopy of deciduous trees will attenuate the incident noise. Plants in general and trees in particular can attenuate the sound by reflecting and absorbing energy in the viscous and thermal boundary layers near the plant surface or by internal damping of sound driven oscillations of branches or stems.

Scattering effectiveness is consistent with the geometry of the scatterers (trunk, branch, leaves). Bigger the scatterers, lower the frequency at which scattering phenomenon becomes effective. Scattering increases with frequency, the transmission paths becomes more and more complex producing absorption of acoustic energy. At low frequencies, this phenomenon is absent, because the wavelength is large compared to the trunks and branches diameter, and the acoustic energy is transmitted easily. The propagation of sound through a large number of scatterers (trunks of trees), in a first approximation, can be treated as a classical diffusion problem if the depth of the tree belt is large and absorption relatively low. It was deduced that about 3dB excess attenuation may be gained if the belt is as wide as deep. Huisman and Attenbourough (1991) noted that the interaction between trunk scattering and ground effect is much more complicated than the diffraction theory and more sophisticated modelling is necessary for complete understanding of experimental data produced by in situ measurements.

2. ACOUSTIC MEASUREMENTS IN URBAN FOREST

A valid comparison between the performances of different types of vegetation cannot be made unless exact description of methodological factors characterizing the noise source and the receiver, such as the height, the placement of source (whether inside the forest or outside and if outside, how far outside) the spectrum of the source and its duration – steady or transient), the size and density of the trees and the atmospheric conditions during the experiments(temperature and wind gradient, relative humidity).

The mechanism of sound propagation in urban forest is summarized in Fig. 3. The atmospheric absorption, the ground, the belt of trees, the wind and temperature gradients attenuate the sound which propagates from the source to the receiver along a specific path. Depending on its nature (soft or hard), ground (Attenbrough 1992) reflections interfere with incident sound producing attenuation or amplification. The belt of tree acts as a sound barrier. Because of scattering, the canopy of the trees can modify the effectiveness of sound barriers. Wind and temperature vertical gradients refract the sound path (up or down) producing sound shadow zones, contributing or not to the effectiveness of sound barriers (Anderson and Kurze 1992).

The factors which have positive influence on the efficiency of forest stands for noise attenuation are: higher stand density, mixed species of trees, larger quantity of leaves. Measurements in summer and in winter for deciduous stands clearly have shown the effect of leaves on attenuation (Price et al.1988). In absence of leaves, the attenuation was considerably low. A peak of attenuation was found at 200 Hz and was attributed to the ground. For frequencies higher then 1000 Hz, the attenuation gradually increased was attributed to the trunks and foliage.

It was found that broad-leaved trees reduce noise better than conifers. Noise abatement is stronger when the foliage extends to close to the ground as in young stands or in the presence of undergrowth. Noise reduction into the stand is a function of distance from the source. To achieve good noise reduction it was suggested to plant rows being felled alternately to maintain dense foliage near the ground. Suitable species with dens foliage are: pyramidal cypress, callitris, thuya, ceratonia, eucalyptus, oak.

It may be important to distinguish between the effect of the solitary tree, a group of trees and a stand forest. Acoustical response of a group of trees is associated with ground effect. The impedance of the ground over which the sound propagates affects the attenuation rate mainly in the 250 … 500 Hz frequency range. Scattering by the branches and absorption by bark and foliage are higher frequency phenomena.

To investigate the modes of vibrations of leaves Martens and Michelsen (1981) used a laser-Doppler vibrometer system. Laser vibrometry is a suitable technique for measuring the vibration velocity in small areas of leaves in a wide range frequency (0 to 100 kHz) without mechanical loading of specimens. The lower limit of the amplitude detection is 1nm. In a sound field of 100 dB sound pressure level (re 20 μPa) vibration velocities were measured between 10^{-5} and $3x10^{-4}$ m/s and it was demonstrated that the leaves behave as linear systems. The vibration velocity of leaves is 1 to 3 orders of magnitude smaller then the vibration velocities of the air particles (5 x 10^{-3} m/s). The leaves behave like plates with different modes of vibration. Only a part of sound energy reaching the leaves will produce vibration energy, the other part will be reflected and diffracted. If the absorption of sound energy is the phenomenon of major importance, the excess attenuation should be linear with the path length and foliage density and could explain the noise attenuation of plants in the environment.

The recapitulation of the experimental data presented by Martens (1981) allows noting that in most 1/3 octave band studied, in beech and ash forest stands the excess attenuation was at least 10 dB / 100m with the receiver and the source at the same height (1.2m) and at least 5 dB/100m with the receiver at 3.9m height. Compared with beech and ash stands, in mixed deciduous stands, a sound window was detected around 2 kHz, and the ground effect was extended more towards the high frequency range, compared with beech and ash stands. In coniferous spruce stands, the highest excess attenuation was measured, such as 10 dB/100 m with the receiver at 1.2 m height and 7 dB /100 m with the receiver at 3.9m. In spruce belt the attenuation, for the same conditions as for spruce stand, were respectively 7 dB /100 m and 4 dB /100 m. As expected, the highest attenuation was found in closed forest stands and not in tree belts. Martens (1981) concluded that trees, belt of trees at least 12 m wide, and forest stands can be efficiently used to abate noise pollution in urban area.

3. TRAFFIC NOISE

The main outdoor sources of noise in modern life are generated by the traffic on streets or highways, by rail transportation and by aircraft.

Models of different complexity were used for traffic noise prediction since 1950. Tendency to unify noise calculation algorithms in Europe was realized with the standard ISO 9613-2. The propagation of highway noise over a forest stand expressed by the variation of the sound pressure level versus the distance has clearly shown the important attenuation produced by the forest stand. In urban areas trees can be used as noise buffers, able to reduce noise with 5 to 10 dB, if some general recommendations are respected (plant trees near the noise source, plant trees/shrubs with dense foliage as close as possible, plant belt trees of 7 to 17 m wide, etc).

Rail transportation is one of the most used systems through the world for passengers and freight within urban and suburban areas. The noise is produced by the propulsion system of the railcars and locomotives, by the interaction between the wheels and rail, and by the aerodynamic connected phenomena. Rail systems generate ground borne vibrations which are important and depend on the resonance frequencies of the train suspension systems and of the smoothness of the wheels and rails. The attenuation effect of belt vegetation is combined with the terrain configuration.

The aircrafts and helicopters generate annoying noise in urban, suburban and natural recreational environment which interferes with the aesthetic quality of the landscape. The noise radiated from the aircraft propagates through the atmosphere and interacts with the forest stand and the ground. Forest stands planted near the airports can be a good solution for the reduction of noise annoyance produced by the continuously growth of aviation traffic.

4. CONCLUDING REMARKS

In our days, urban forestry represents a synthesis of policy, planning, landscape architecture and environmental science. Urban trees add important beauty to our cities. The world becomes ever more dominated by the sounds of humans and machines because of the urbanisation process. The continuous development of urbanisation implicitly determined the evolution of urban forestry. Mixing species of trees having a larger quantity of leaves in high density stands may improve the efficiency of forest stands for noise attenuation in urban area. Foresters must be involved in a positive view of the urbanisation seeking to understand the interaction between the trees and the urban environment in a new specific ecosystem.

REFERENCES

Anderson GS, Kruze UJ (1992) Outdoor sound propagation. In “Noise and vibration control engineering. Principles and applications”. Eds . L Beranek and I.L. Vèr, John Wiley & Sons, New York : 113-144

Attenbrough K (1992) Ground parameter information for propagation modeling. J.A.S.A.92 : 1042 - 1046

Bucur V (2005) Urban Forest Acoustics . (in preparation) for Springer Verlag - Heidelberg

Embelton TFW (1996) Tutorial on sound propagation outdoors. . J. A. S. A. 110: 31-48

Fang CF, Ling DL (2003) Investigation of the noise reduction provided by tree belts. Landscape and Urban Planning 63 : 187-195

Huisman WHT, Attenborough K (1991) Reverberation and attenuation in pine forest. J. A. S. A. 91 : 2664-2677

Kellomäki-S; Haapanen-A; Salonen-H (1976) Tree stands in urban noise abatement. Silva-Fennica. 1976, 10: 3, 237-256

Lyon-RH; Blair-CN; DeJong-RG (1977) Evaluating effects of vegetation on the acoustical environment by physical scale-modeling. Proceedings of the conference on metropolitan physical environment. General-Technical-Report,-Northeastern-Forest-Experiment-Station,-USDA-Forest-Service. 1977, No. NE-25: 218-225

Martens MJM (1981) Noise abatement in plant monocultures and plant communities. Appl. Acoustics 14:167 – 189

Martens MJM, Michelsen A (1981) Absorption of acoustic energy by plants leaves. J.A. S. A. 69:303-306

Price MA Attenborough K, Heap NW (1988) Sound attenuation through trees: measurements and models. J. A. S.A. 84 : 1836 - 1844

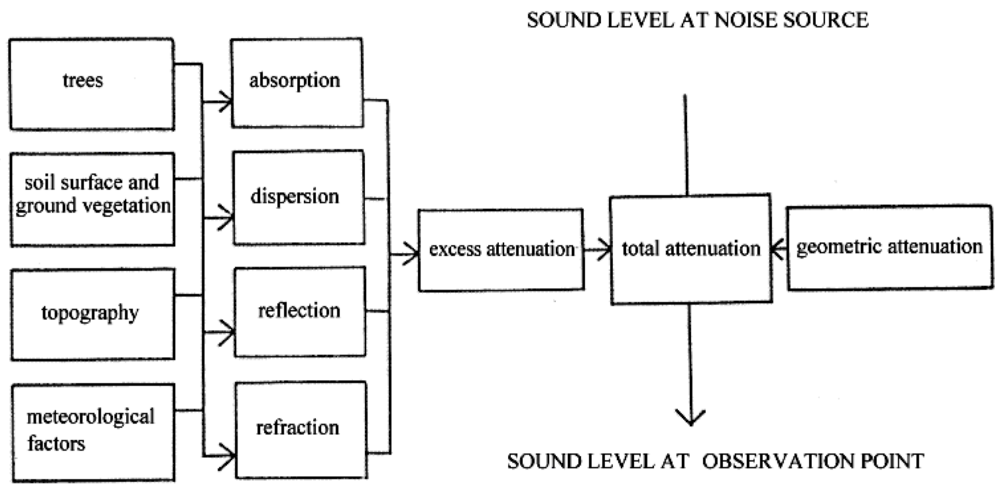
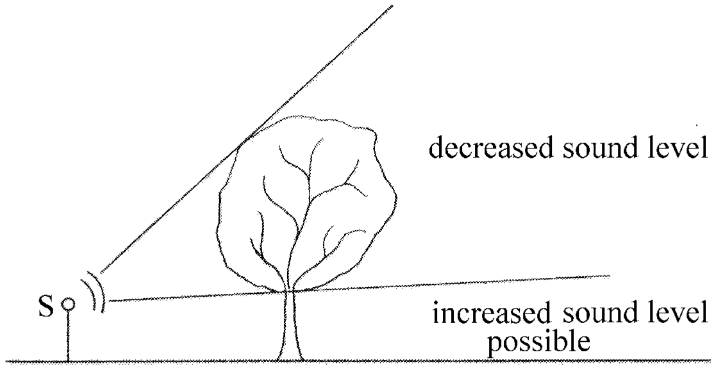
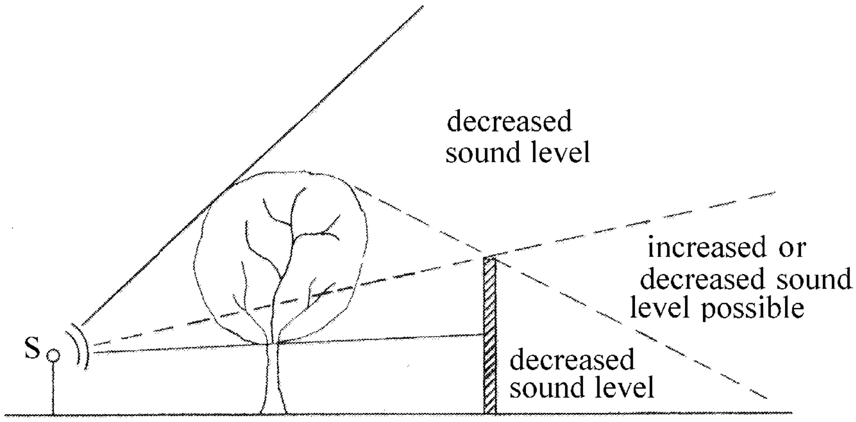


Figure 1. Contribution of several factors (trees, soil, topography, meteorology) to total noise attenuation in a stand (Kellömaki et al 1976)



the screening of sound by vegetation



effects of vegetation upon barrier performance

Figure 2. Screening of sound by a tree (Lyon et al. 1977)

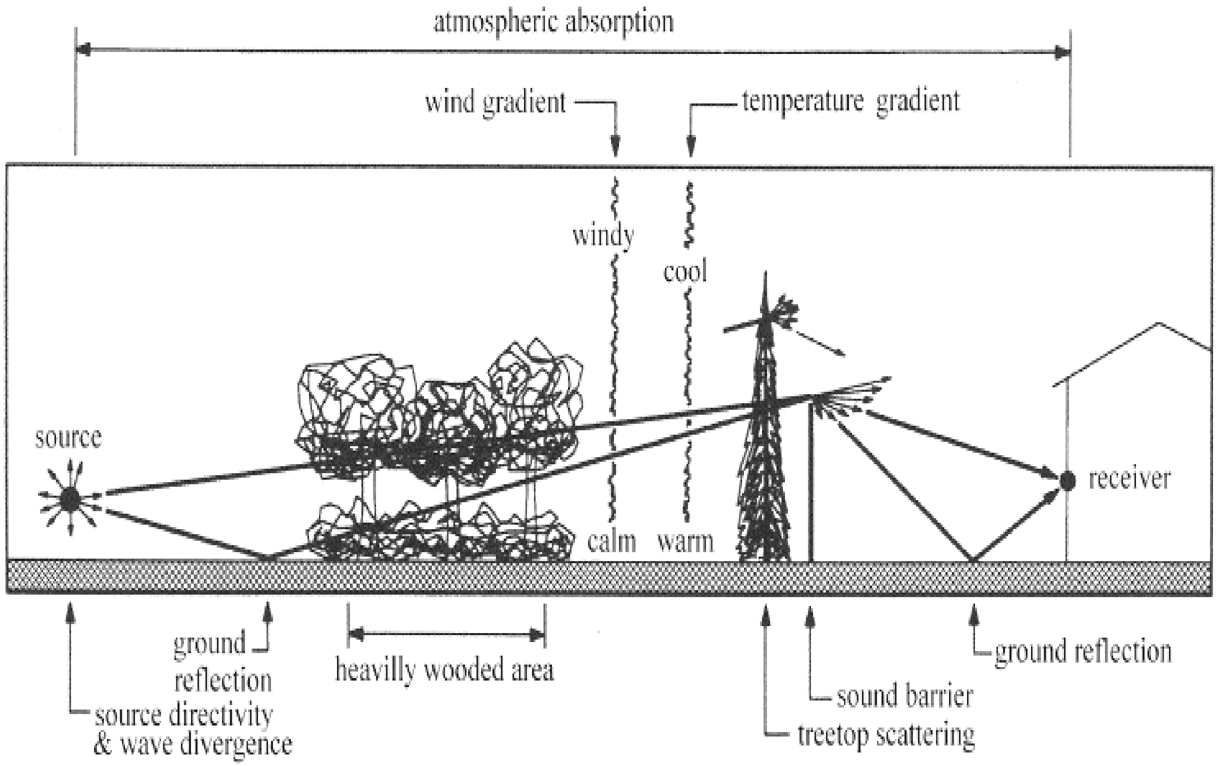


Figure 3. Outdoor sound propagation (Anderson and Kurze 1992)