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Laboratory Test of Sound Absorption of Vegetation

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ABSTRACT

In street canyons, with increasing absorption and diffusion of street boundaries and furniture, the sound attenuation along the length could be increased. Well designed and placed vegetation could have similar effects. Therefore, knowledge of such acoustic properties of vegetation is required to accurately predict sound propagation and optimise the use of green surfaces for reducing the noise impact. However, measurements and modelling of such acoustic properties of vegetation are still rather limited. In this study absorption properties of some typical vegetation samples used in European streets have been measured in a reverberation chamber in accordance with ISO 345:2003 and using a PU probe. It has been shown that for both bedding plants and evergreens the absorption is generally over 0.5 at middle and high frequencies, which is rather effective in noise control for urban environments. The effects of basic plant characteristics have been shown by comparing different plant types, although a more systematic study is still needed. For both the reverberation chamber method and the PU probe method, more development is still needed for producing robust results.

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1. INTRODUCTION

Green elements such as trees, shrubs, bushes and green roof plants have recently been paid more attention as a natural way to reduce noise levels in the urban environment. Vegetation is a complex medium consisting of air, soil and plants that themselves contain stems, trunks, branches and foliage. Thus the use of green elements to achieve effective noise reduction in urban spaces requires systematic parametric studies of the acoustic properties of vegetation. The acoustic properties of vegetation have been studied in terms of ground effect, multiple scattering by leaves, branches and stems, and sound attenuation through bushes and trees. A good review can be found in [1].

This research has two objectives. The first is to determine the changes in reverberation time (RT) caused by typical plants (bedding and evergreen) in a reverberation chamber and to determine absorption coefficients of the plants. This is measured according to ISO 345:2003 [2]. Effects of various factors on the absorption properties of plants are also analysed, including frequency bands, plant sample size, plant spacing (density), and geometrical and biological characteristics. The second objective involves a study of the reliability of a PU (pressure-particle velocity) probe method [3-6] for measurements of the absorption coefficient of vegetation. In preliminary studies of the authors [6] the PU probe has already been applied to measure the absorption coefficient of grass and a hedge. Good differentiations in absorption coefficient of individual structures were observed for frequencies >260Hz. It was also found that in the case of grass the absorption coefficient at low and middle frequencies (< 3kHz) was relatively low, between 0.3 and 0.6.

2. METHOD

The selected samples were bedding plants, *Viola x wittrockiana* (common name *Pancy*) and *Primula vulgaris* (common name *Primrose*), and evergreens *Buxus Sempervirens* (common name *Buxus*). These species represent typical vegetation grown along roadsides and in street canyons in Europe [7, 8]. During the measurements the plants were put in pots with soil.

Table 1 presents the characteristics of plants and pots used in the measurements, under different setting conditions. Leaf areas were calculated from the relevant pixel areas in digital images. The number of leaves on a plant representative of those in the species sample was used to calculate total leaf area per plant. Plant volume of stems and foliage was measured using a water displacement method. The plant percent biomass (above soil level) is equal to the *dry* weight (times 100) divided by the *fresh* weight. Dry weight was obtained after oven drying, to remove all the water [9].

Table 1. Characteristics of plants and pots used in the measurements of absorption coefficient.

Plant or sample	Leaf area, 10^{-6} m^2	Total leaf area per plant, m^2	Volume per plant, 10^{-3} m^3	Biomass, %	Plant height, m	Pot height/ diameter, m	Number of pots/m^2	Sample area, m^2
Pancy	876	0.03	0.023	31	0.15	0.07/0.1	40	6.2
Primrose	3253	0.05	0.015	11	0.07	0.07/0.1	40	4.3
60% Pancy & 40% Primrose	1827	0.05	0.020	21	0.12	0.07/0.1	40	9.5
Buxus dense	98	0.17	0.112	41	0.3, 0.3	0.15/0.19	16	4.0
Buxus not dense							8	9.0

This experiment was designed to examine the influence of the plant sample area, density, and geometrical and biological characteristics on RT in the chamber and on the absorption coefficient of the plants. All three samples of bedding plants had the pots arranged very tightly, while two densities of the evergreen plants were tested. Some photos of the plant arrangements are shown in Figure 1.

Figure 1. Samples of pancy and primrose (left), buxus dense (middle) and buxus not dense (right).

Measurement of the plant sound absorption properties took place in a reverberation chamber of dimensions 12m x 4m x 4.5m at the University of Sheffield. The plants were located on the floor. The measurements according to ISO 345 used a dodecahedron speaker, two ¼" condenser microphones and a 01dB audio acquisition kit. The dodecahedron was put at two locations in the corners of the chamber and four microphone positions at distances greater than 1m from the test specimens were chosen [2]. An MLS signal of the 4^{th} order was used as the test signal. The test was repeated three times for each speaker-microphone position. For the second set of experiment the setup included a PU match probe, a signal conditioner, a two channel sound card, and a loudspeaker point-source [3]. The distance from the sound source to the PU probe was 26cm and the distance from PU probe to the sample was 2cm. The probe was swept along the surface of the plants. Since it was difficult to reach across the whole area, four measurements were performed each time that covered the four quadrants of the sample.

3. RESULTS

Experiment 1 - Test according to ISO 354

Figure 2 shows the RT in 1/3 octave bands averaged over the source-receiver positions under various conditions. It can be seen that both types of plant reduce RT in the reverberation chamber dramatically with the highest drop occurring within the frequency range of 250Hz to 1.6kHz. According to the study of Wong *et al* [10], it is possible that the drop in RT at lower frequencies is mainly due to absorption by the soil, while at the frequency range of 500Hz to 1.6kHz it is due to absorption by the foliage [11]. The RT reduction at higher frequencies (>1.6 kHz) is relatively small, perhaps due to the mechanism of scattering of sound energy by leaves [1,11].

RT generally increases with the increase in the area covered by the bedding plant samples. This is in agreement with the results by Watanabe and Yamada [12]. On the other hand, it is interesting to note that between the dense and non-dense samples of Buxus, no significant difference was observed, although the area covered by the plants is approximately doubled.

Measured absorption coefficients are presented in Figure 3. Although the maximum absorption is reached within the frequency range from 500Hz to 1.25kHz, the absorption coefficients obtained for all samples except the non-densely arranged evergreen plants are rather overestimated, greater than 1.0. This is perhaps caused by the edge effect that might be reduced by increasing the sample area to at least 10m^2 [2]. The edge effect could also be caused by sound scattering from the pots, which can be resolved by enclosing the entire sample area in a frame constructed from a reflective material [2].

By comparing dense evergreen sample and dense bedding plants, it can be seen that the absorption coefficients of the former is considerably higher. This is mainly caused by the basic characteristics of plants, such as leaf area, plant total leaf area, plant volume (of stems and foliage) and biomass, as can be seen in Table 1. A more systematic study would be needed with more vegetation types.

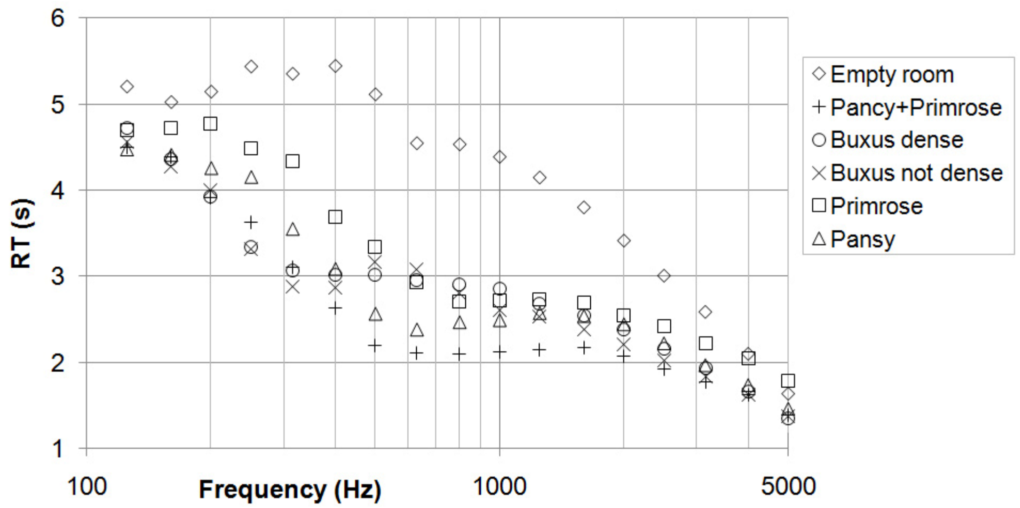

Figure 2. RT in the reverberation chamber in empty condition and with various plant samples.

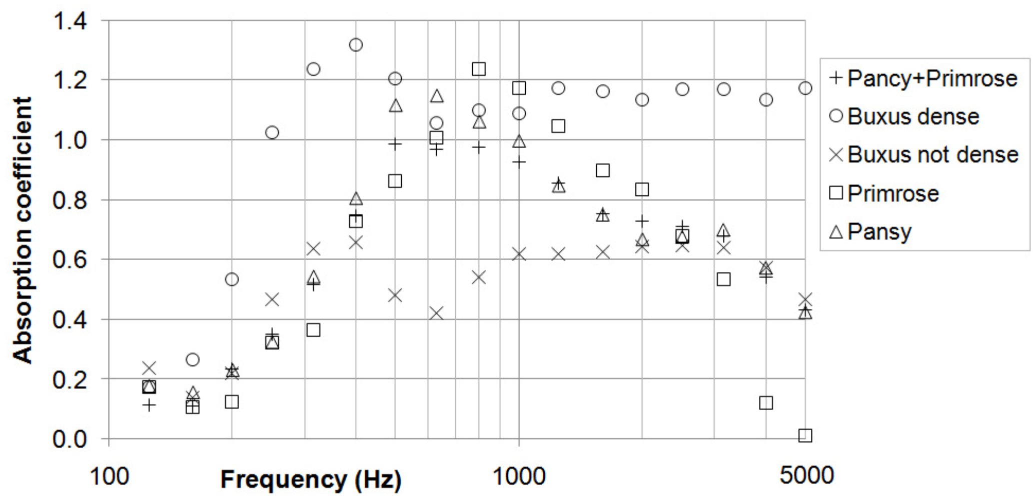

Figure 3. Absorption coefficients of the tested plants of different types and different arrangements.

Experiment 2 - <u>Test with the PU probe</u>

In the second experiment, absorption coefficients for the two evergreen plant samples used in Experiment 1 were measured with a PU probe. Figure 4 compares the measured results with the two methods, where for the PU probe method, the results are based on the average absorption over four areas that were swept with the probe. The measured absorption coefficient by the PU probe method is close to 1 at frequencies above 315Hz, for both samples. Perhaps this is because in the case of the impedance measurements on which the PU probe method relies it is assumed that the energy absorbed can be derived from the energy reflected if there is a rigid back-plate and a defined surface of the tested sample [4]. Since the vegetation was relatively far from the floor (45cm), leakage due to scattering of the spherical sound waves through the leaves would have affected the measurements. This would lead to an overestimation of the absorption values. Also, because of the uneven height of the plants, it was not possible to define the proper distance from the PU probe to the surface of the vegetation, also a crucial parameter for the calculation procedure with this device. For the above reasons, the results of the PU probe method is close to that in experiment 1 with dense sample, as can be seen in Figure 4. Therefore, while preliminary studies by the authors [6] have shown that in the case of grass the PU probe provides a rather reliable measure of the absorption coefficient in a wide range of frequencies, caution must be taken in using measurements from relatively tall plants for which the distance from the PU probe to a rigid back-plate is too large. The surface of the plants has also to be even.

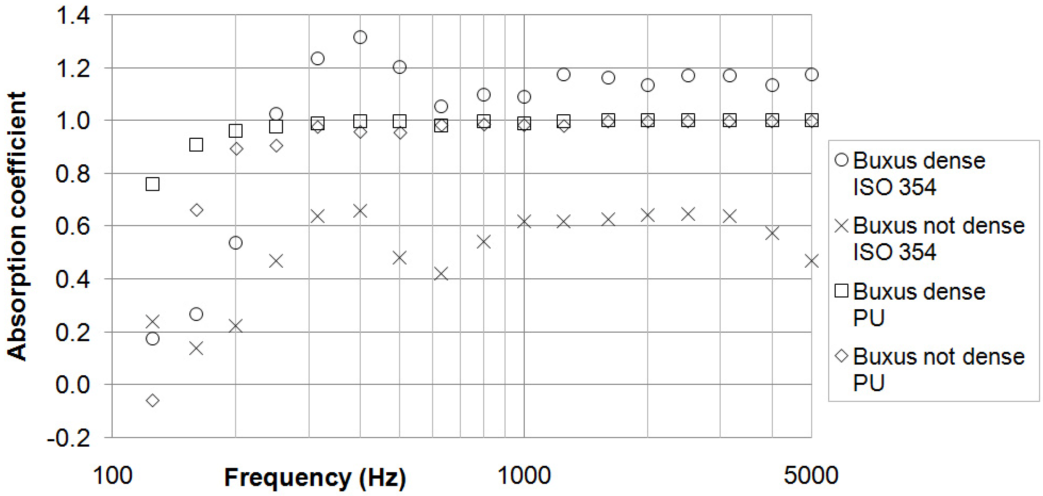

Figure 4. Absorption coefficient of the two samples of Buxus plants measured according to ISO 354 and with a PU probe.

4. CONCLUSIONS

In this paper the absorption properties of two types of plant typically grown in European streets have been initially investigated in a reverberation chamber using the method in ISO 345:2003 and by applying a PU probe. The plants varied in terms of their geometrical and biological characteristics.

All the samples tested provided a drop in the RT, and the equivalent absorption is generally over 0.5 at middle and high frequencies, which is rather effective in noise control for urban environment. The absorption could be caused by the soil in the pots as well as foliage. The effects of basic plant characteristics have been shown by comparing different plant types, but a more systematic study is still needed.

Strong edge effect has been shown in the ISO 345 method, so that more consistent method would be needed for comparing different plant types and different arrangements of a given plant. With the PU probe method, the results are very sensitive to the accuracy of the probe-sample distance as well as the distance between the probe and the rigid back-plate (the floor in the case of a reverberation chamber), and a robust method still needs to be developed.

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