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SOUND ABSORPTION PROPERTIES OF TROPICAL PLANTS FOR INDOOR APPLICATIONS

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The paper presents the experimental results of sound absorption coefficient measurements of several tropical plants, including fern, baby tears, begonia, maidenhair fern and ivy. All these plants live in tropical underbrush in conditions of low lighting, warm temperature and high relative humidity, conditions that can be often found inside common buildings. A vertically mounted impedance tube with a diameter of 100 mm is used in accordance with ISO 10534-2 method to determine the absorption coefficient spectra. A substrate made of coconut and perlite soil for hydroponics is used with all the samples. It is chosen because of its high porosity and, as a result, good sound absorption properties. The paper also presents the random incidence absorption coefficient spectra which were measured in a reverberating room in accordance with ISO 354. The aim of this research is to investigate the feasibility of introducing absorptive panels made of living plants as a replacement for conventional man-made acoustic treatment of surface used to improve the acoustic quality of indoor spaces.

1. Introduction

The integration of green systems in architecture has been used for centuries. The first (probably fortuitous) examples date back to the 11th century BC, when Vikings used to build their huts with wood and peat bricks[1]. These components allowed the development of low growing vegetation, whose roots created a monolithic structure with the peat bricks stiffening the structure. Later, the use of green elements in architecture gains a purely aesthetic role, as demonstrated by the Hanging Gardens of Babylon (7th – 6th century BC), the Hadrian's mausoleum (now Castel Sant'Angelo, 2th century BC) in Rome or the hanging gardens in the roman villas, as the one in Ercolano[2]. In the Middle Age hanging gardens loses their aesthetic role in favour of functionality: they are used as vegetable gardens in convent's cloister or on the top of city walls (as in the Italian city of Lucca) to increase the defence efficiency against the opposing armies. In the Renaissance age green elements are again used as ornament of palaces: examples can be found in Giovanni dei Medici's villa in Fiesole (1451) or in Piccolomini Palace in Pienza (1460), both in Italy[3]. The birth of modern green walls dates to the first patent deposited by Stanley Hart White in 1938[4]: also in this case, the proposed solution represents an ornamental solution for architects, unlike green roofs, whose positive environmental and hygienic impacts were stressed in the first half of the 20th century by famous architects, such as Alvar Aalto, Frank Lloyd Wright and Le Corbusier.

Coming to our days, the revolution of green walls happens in the ‘80s thanks to the ideas of the French botanist Patrick Blanc[5], who developed lightweight and modular structures adaptable to every façade. This is made possible by the absence of a soil substrate: the plants can indeed live only with water, oxygen and carbon dioxide and in this configuration the roots develop only in the upper layer of the structure, without damaging the structure underneath. Some of his most famous green walls are those covering the facades of the Museé du Quai Branley in Paris and the Caixa Forum in Madrid.

Green roofs have been intensively studied in the last decades, showing that they can be very effective in reducing the Urban Heat Island (UHI) effect, in improving air quality and in giving an extra protection to buildings in shielding heat fluxes and electromagnetic waves; also the acoustic performance have been evaluated[6]; on the contrary green walls have often been seen as pure decorations, with the unique functional application represented by green road noise barriers.

Only in the last years researchers have been focusing their attention on green walls; also the acoustic performance is examined, as done in the EU funded Hosanna Project[7] which focused on outdoor noise control. Unlike many other works, this paper studies the use of green systems for the acoustic treatment of indoor spaces. It is believed that these systems can potentially replace traditional or even sustainable man-made acoustic absorbers[8] because of their good aesthetic and restorative effects[9,10].

2. Sound absorption of greenery

Even if the general opinion is that greenery is not a good sound absorber, it was demonstrated that vegetation surfaces are able to absorb up to 50% of incident sound energy[11]. A review of the interaction between sound and vegetation can be found in the outcomes of the Hosanna Project[7]. The viscous absorption effects in crops were studied by Aylor[12]. The absorption effects related to leaves vibration were studied by Martens[13] and by Tang *et al*[14] who showed that this phenomenon contributes to the absorption at frequencies higher than 1 kHz. More recently Horoshenkov *et al*[15] measured the acoustic absorption of 5 different types of low growing pants in the presence and absence of soil substrates. Their results showed that morphological parameters, such as leaf area density and dominant leaf angle, are the main factors which affect the visco-thermal acoustic absorption by plants in the frequency range of 50 – 1200 Hz. Ding *et al*[16] studied the influence of leaves presence on the acoustic absorption of a porous substrate. The impedance tube measurements and theoretical predictions for the set up their adopted suggested that there is no influence in the low frequency range (below 250 Hz). On the contrary, it is demonstrated that there is an increase in the absorption coefficient at middle frequencies (500-2000 Hz) and a decrease at higher frequency (above 2000 Hz) due to the vibration and shielding effect by the leaves.

The purpose of this paper is to carry out laboratory experiments to understand better the ability of different plants to absorb noise in the presence of soil.

3. Description of the tested plants

The species selection is based on three fundamental parameters which were identified with the help from the Department of Agriculture of University of Perugia. These are: (i) ability of a plant to grow in indoor climate conditions, (ii) ability of a plant to survive without direct sunlight, (iii) ability of a plant to branch in horizontal conditions. The first two parameters are fulfilled in thermopile plants which are common in tropical climates and in the warmer zones of temperate climates. These climates have temperature and humidity conditions very close to the indoor spaces conditions. Furthermore, it can be possible to find habitats in which plants species grow naturally in horizontal position, as in waterfall sides or river blanks (Figure 1).

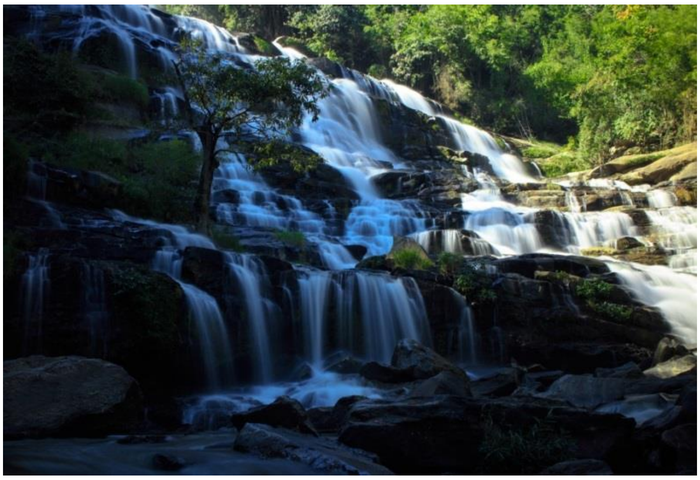

Figure 1. Mae Ya Waterfall in Doi Inthanon National Park, Chiang Mai, Thailand.

The selected thermopile species are *Nephroepis Exaltata* (Fern), *Helxine soleirolii* (baby tears), *Begonia Rex* (Begonia) and *Adiantum capillus-veneris* (Maidenhair Fern) (Figure 2). The species *Hedera helix* (Green Ivy), which is not a thermopile but fulfils all the selection parameters, was also selected. It is widespread in several EU countries and is able to survive in different climate conditions. The investigated soil was a low-density substrate supplied by Perlite Italiana s.r.l. which is used in hydroponics cultivations. The substrate is made of perlite (30%) and of coconut fibres (70%).

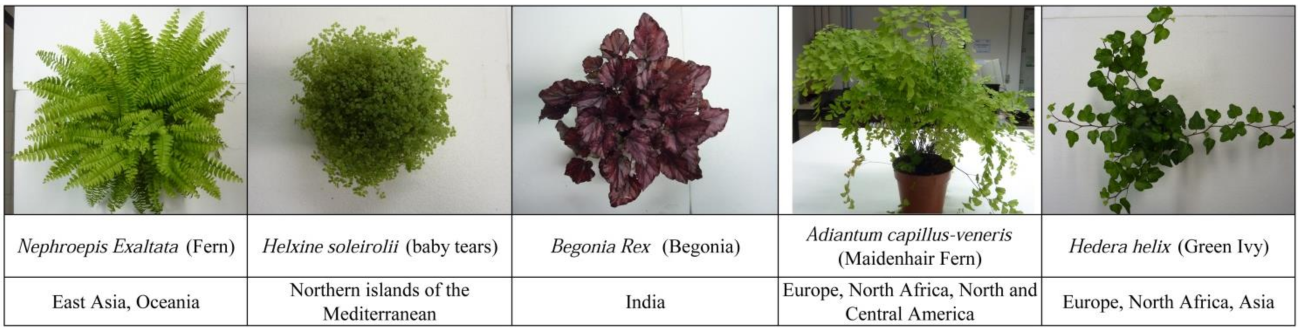

Figure 2. The five selected species of plants.

4. Measurement of normal incidence absorption coefficient

4.1 Method

The absorption coefficient of the five different samples were obtained using a standard impedance tube in accordance with ISO 10534-2 method[17]. The 100 mm diameter samples holder allows to investigate the frequency range 50 – 1600 Hz[18]. Higher frequencies were not analysed because of the samples dimensions that did not fit in a 29 mm diameter holder. The impedance tube was hung on the wall to keep the specimen (substrates and plant) upright during the measurements. The samples leaves were trimmed to allow the plant to fit in the 100 mm tube, also the roots were cut from the plants. Each of the five plant species was measured three times in the impedance tube, extracting and replacing the sample in the tube taking care of not compressing the substrate at the bottom. The absorption coefficient of a 10 cm layer of low-density soil substrate (Perlite Italiana s.r.l. substrate) was measured in a separate experiment to provide a reference set of data.

4.2 Results

The results suggest that all the species analyzed are able to absorb a relatively high proportion of the incident acoustic energy. However, it can be also observed that the main absorber is the layer of substrate which is able to absorb up to 80% of incident sound energy. The presence of foliage helps to improve the low (below 500 Hz) and higher (above 1000 Hz) absorption performance of the layer of soil substrate by 10 – 20%. As the graph shows, some species are more efficient than others, in fact some tested plants contribute to the acoustic absorption for the whole frequency range, other worsen the acoustic absorption in several frequencies (Figure 3). In particularly Begonia shows a pejorative behavior in the frequency range 650 – 1100 Hz, despite it is able to absorb up to 97% of incident acoustic energy at high frequencies (1600 Hz). The Green Ivy worsens the absorption spectra at frequencies above 850 Hz which is consistent with the findings of Horoshenkov *et al*[15]. The Fern (*Nephroepis Exaltata*) specimen is able to absorb up to 98% of incident acoustic energy at frequencies close to 1600 Hz. Also the baby tears provides a very good absorption spectra, increasing the soil substrate acoustic absorption coefficient for the whole investigated frequency range. Despite the very small thickness of the sample (about 3 cm) the baby tears is able to absorb up to 90% of incident acoustic energy.

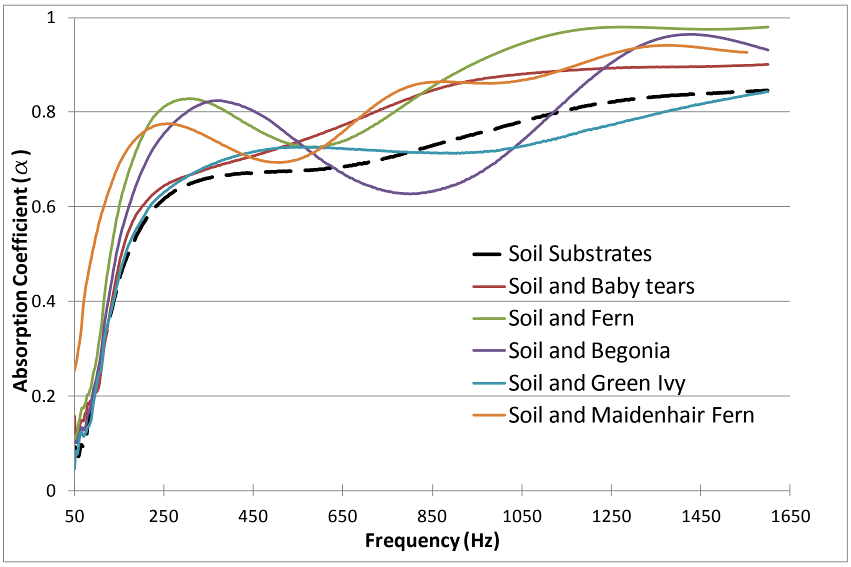

Figure 3. Acoustic absorption coefficients of the five species of plants tested.

The most efficient species among tested samples are certainly the fern, which is able to absorb up to 98% of the incident acoustic energy, and the baby tears, which does not show the highest absorption but provides an important contribute in the absorption for the whole frequency range. In order to characterize acoustically in a complete way these two plant types, further measurements were carried out in diffuse field conditions in a reverberation chamber.

5. Measurement of diffuse field absorption coefficient

5.1 Method

After performing measurements on small samples using an impedance tube, the diffused field absorption coefficient of larger samples was measured in the reverberation chamber of the University of Perugia in compliance with ISO 354 method[18, 19]. The chamber dimensions are 4.6 m depth, 4 m width, and 2.9 m height. Therefore the chamber volume is 53.36 m^3, lower than the one requested by ISO 354. The acoustic set-up consisted in calibrated microphones, amplifier, omnidirectional source, data recording and processing system and a thermohygrometer. The measurement positions of microphones and omnidirectional source were chosen in accordance with ISO 354 prescriptions.

Each measurement configuration had an omnidirectional source position with three different microphone positions. Despite of the low volume of the chamber, a variable number of diffusers were installed in the chamber at various positions in order to achieve satisfactory diffusion field characteristics as suggested in the Annex A of ISO 354. Using a suitable test specimen, the different diffusers configurations were tested in accordance with previous works of the Authors[20]. It was observed that the best conditions of diffuse sound field were achieved with 12 diffusers arranged at the four room corner. In order to fix the samples to the wall and support the substrate and the plants, a wood structure was built. The side perimeter of the wood element was covered with a thin Plexiglas layer to avoid any influence of the wood in the acoustic absorption. The tested configurations were three: (i) Soil and Baby tears in different greenery coverage densities (25, 50 and 90 species installed on the sample; Fig. 4); (ii) Soil and Fern in different greenery coverage densities (25, 50 and 90 species installed on the sample; Fig. 5); (iii) Soil with Baby tears and Fern (45 baby tears species and 45 Fern species installed on the sample). The dimension of the tested samples was 1.06 x 1.06 m and 12.5cm in thickness.

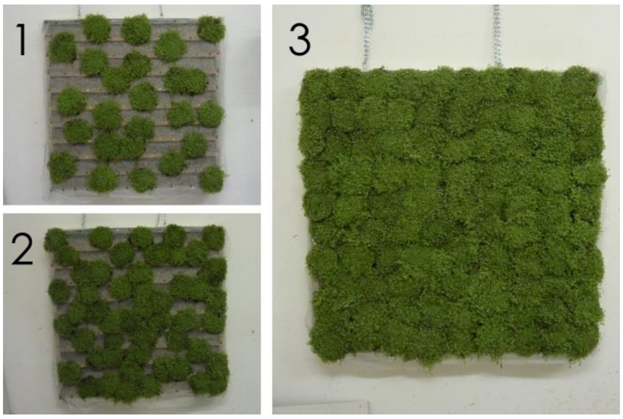

Figure 4. Baby tears configurations.

Figure 5. Fern configurations.

5.2 Results

The measured diffused field absorption coefficient can be higher than the unit, which is physically unrealistic. This relates to the smaller dimensions of the tested samples and smaller volume of the reverberation chamber than those recommended in the ISO 354. Nevertheless, the obtained data enable us to observe the relative trend in the absorption coefficient of the soil substrate with and without the plants. Because of the small size of the room the results are significant above 200 Hz.

The results confirm that the main absorber is the substrate soil, which provides a very high acoustic absorption in the frequency range of 500 – 600 Hz. The greenery coverage improves the acoustic absorption only in high density conditions, i.e. when a large number of plants is installed on the sample. Specifically, the configurations with 25 and 50 baby tears samples show a fluctuating behavior (Figure 6). The plants foliage, in such densities, improves the substrate acoustic absorption at some frequencies, while is pejorative at others. These variations are not significant (an increase/decrease of substrate acoustic absorption of 5-8%). The highest increase in the acoustic absorption occurs in the frequency range of 800 – 1600 Hz. This trend occurs again in the last configuration with 90 baby tears installed. In this case, plants improve the substrate absorption coefficient for the whole frequency range analyzed. It was observed an increase of 11% of the substrate sound energy absorption.

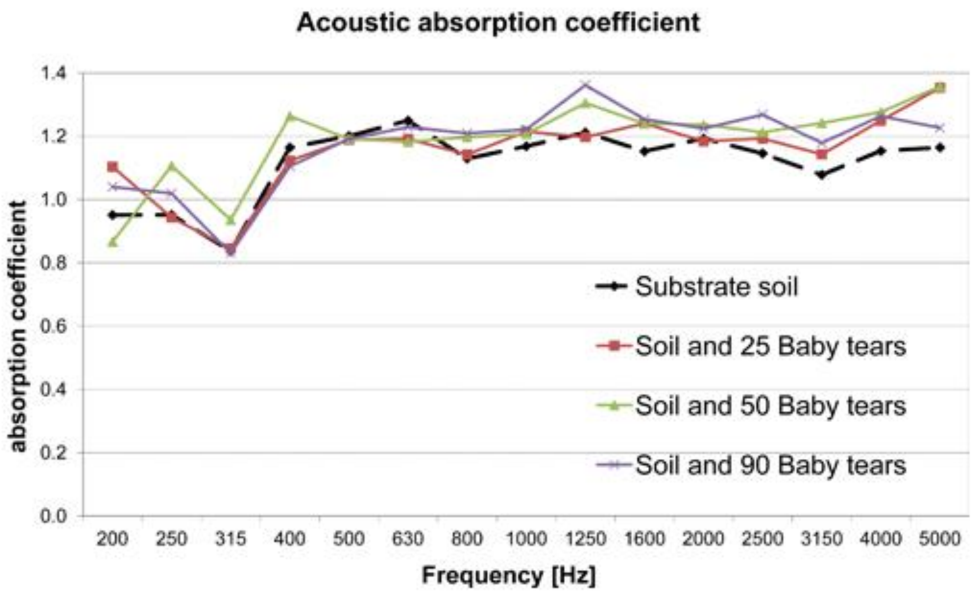

Figure 6. Acoustic absorption coefficients of Baby tears configurations.

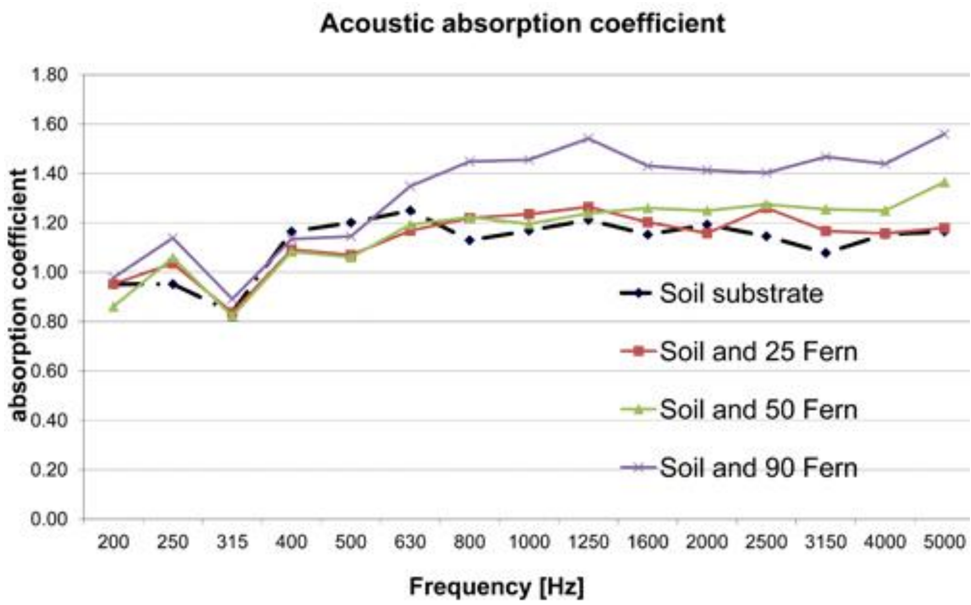

Figure 7. Acoustic absorption coefficients of Fern configurations.

The configurations with 25 and 50 fern samples do not show a noticeable change in the spectrum of the diffused field absorption coefficient (see Figure 7). The greatest increase in the acoustic absorption coefficient is observed in the frequency range of 800 – 1600 Hz. The 90 fern configuration improves the substrate acoustic absorption up to 25% of acoustic energy absorbed, within the frequency range 800 – 1600 Hz.

Figure 8 shows the absorption coefficient for a soil sample with and without 45 specimens of baby tears and 45 specimens of fern samples. The highest acoustic absorption occurs within the frequency range 800 – 1600 Hz, where the plants species in combination are able to improve the substrate's acoustic absorption by up to 12%.

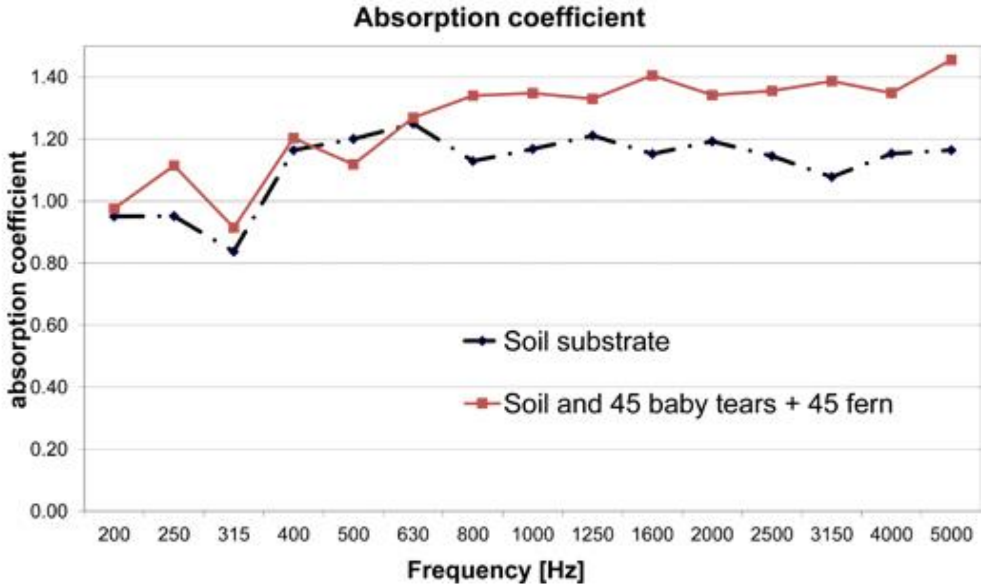

Figure 8. Acoustic absorption coefficients of Baby tears and Fern configurations.

According to Wong *et al*[11], the RT drop at lower frequencies is due to substrate soil (200-500 Hz), while at higher frequencies the reduction is due to the foliage. Also the acoustic absorption coefficient behaviors are very similar.

6. Conclusions

The measurements, both in normal incidence and in diffuse field, showed that the main absorber is the substrate soil, which is able to capture a high quantity of acoustic energy. The presence of the plants becomes useful only when a large number of them is installed on the sample, otherwise is even pejorative within some frequency ranges. Using the impedance tube, fern and baby tears were found as being the most efficient plants among tested species. The baby tears with soil demonstrated a capability to absorb up to 90% of incident acoustic energy, while the fern demonstrated the capability to absorb up to 98%. In acoustic diffuse field conditions, in the reverberation chamber of Perugia, these two species were tested with soil, using a wood structure as support (1,06 x 1,06 x 0,125 m). The most efficient plant is the fern which improves the substrate acoustic absorption by the 25%. Future developments of this work will take into account the influence of substrate humidity on the absorption coefficient and the influence of morphological changes of the plants on the absorption coefficient such as the leaf area density and angle of leaf orientation. Larger samples will also be tested a bigger reverberation room, to avoid the physical inconsistency of Figures 6, 7 and 8.

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