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An application of a parametric transducer to measure acoustic absorption of a living green wall

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ABSTRACT

This work reports on a new method to measure the absorption coefficient of a Living Green Wall (LGW) *in-situ*. A highly directional parametric transducer and acoustic intensity probe are used to make this method robust against background noise and unwanted reflections. This method is tested under controlled laboratory conditions and *in-situ* on a real green wall. The methods is compared favourably against impedance tube data obtained for porous media which properties are relatively easy to measure using a standard laboratory setup. The new method is an alternative to the ISO354-2003 and CEN/TS 1793-5:2016 standard methods to measure acoustic absorption of materials.

1. Introduction

There has been strong evidence that some living plants (foliage) are able to absorb a considerable proportion of the energy in the incident sound wave. Some of this evidence were obtained through the standard laboratory experiment [1], some were derived through the application of a model (e.g. [2,3]) and some were collected *in-situ* [4]. However, there is still no valid theoretical model which is based on clear physics and which can explain the observed absorption spectra in a sufficiently broad frequency range. The evidence assembled so far suggest that three main mechanisms are responsible for the absorption of sound by living plants. In the lower part of the audible frequency range (e.g. below 100–400 Hz) the thermal dissipation mechanisms are important [5]. In the medium frequency (e.g. 400–2000 Hz) where the acoustic wavelength is still much larger that the characteristic leaf dimension (e.g. 15–250 mm for typical plants [3]) the viscous dissipation is the prime absorption mechanism [2,6]. In the higher frequency range (e.g. above 1–2 kHz) where the acoustic wavelength becomes comparable or smaller than the characteristic leaf dimension, the leaf vibration and multiple scattering begin to contribute to the dissipation of the energy in the incident sound wave [3,6].

One obstacle to the development of a unified model for sound propagation through foliage is the lack of reliable experimental data on the acoustic reflection/absorption coefficient spectra for a representative range of acoustic frequencies and angles of incidence. These data can then be related to the morphological characteristics of plants which can be directly measured so that a robust model can be developed and tested through a reliable experiment. An apparent lack of data on the acoustic reflection/absorption coefficient spectra for plants can be explained by the difficulties in measuring the absorption by plants in the laboratory or *in-situ*. This difficulty in laboratory conditions relates to the standard ISO 354 test [7] that requires 10 m^2 area of living plant or LGW specimen transported and installed in a reverberation chamber which is a rather cumbersome and expensive procedure. The alternative, ISO 10534-2 test [8] does not allow for a large enough LGW specimen to be tested in a broad enough frequency range. The difficulty of measuring the absorption of LGW or individual living plants *in-situ* is a lack of reliable standard methods for measuring the absorption of complex surface geometries such as plants and the strong influence of the ground from which these plants are grown. The BS 1793-5:2016 [9] method relies on an omni-directional source and microphones. As a result, it suffers from the interference between the sound reflected from the LGW, its edges and the ground. It is also recommended only for flat, homogeneous samples so that its application to volumetric absorbers such as living plants is questionable.

The aim of this work is to apply and validate a method which is able to measure the acoustic absorption of a large specimen of a

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vertical placed living plant in a broad frequency range which is representative of the spectrum of noise emitted by traffic and other common sources of noise. This method requires a parametric transducer and intensity probe which sensitivities are highly directional. In comparison with the BS 1793-5:2016 method [9], the method proposed in this paper is less prone to the effect of the ground reflection or to the edge effects and it can be used either in a laboratory conditions or *in-situ*. Laboratory applications of parametric transducer have been reported before to measure the complex reflection coefficient of flat material samples of limited dimensions [10,11] and sonic crystals [12] at normal and oblique angles of incidence. In this respect, the novelty of the parametric transducer method used in this paper is three-fold. Firstly, this method is applied to measure the absorption of a green wall which surface is far more complicated. Secondly, we use the sound intensity probe and signal deconvolution which makes this method particularly resistant to environmental noise. Thirdly, this method is now applied outdoors to a realistic section of a green wall which is typical to the conditions under which the acoustic absorption of green walls need to be measured.

The paper is organised in the following manner. Section 2 describes the design of the Living Green Wall's (LGW) used in the experiments. Section 3 describes the experimental setup and specimen characterisation procedures. Section 4 presents the results. Section 5 draws conclusions.

2. Green wall arrangement

LGW module system for this work was provided by ANS Group Global Ltd - Living Wall & Green Roof Specialist company. The wall is arranged in the form of a rectangular heavy duty plastic modules which measure 100 mm deep, 250 mm wide and 500 mm tall with 14 compartments for plants (7 compartments tall and 2 compartments wide as shown in Fig. 1 – right). All modules are identical and have a special hook catchment at the back which allows the modules to be hung on the wall. There is a hood at the back to allow for water pipeline installation and to provide a click-in system for the module placed on top. There are trenches at both sides of the module to allow for firm fixing with screws. In total 8 modules and 96 plants are required to form a 1 m^2 of the wall. On average, when watered 1 m^2 of green wall section weighs 72 kg.

Fig. 1. Living Green Wall module, with plants and empty (ANS Group Global Ltd). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

The modules are cladded on to the wooden rails that are firmly attached to the wall and/or facade. In between of the wall and the rail a specialised waterproof membrane is stitched to protect the building wall from excess water and damp (see Fig. 2). Advanced green wall options offer wireless wall moisture control with automated on/off water supply systems. When constructing the wall, the modules may come on site pre-planted, or alternatively planting can be done on site. The choice of plants for the Living Green Wall (LGW) is down to the designer's preference. However, factors such as the south or north side facing building wall, average temperature, humidity, average rainfall and wind are normally taken into account.

3. Experimental setup

3.1. Acoustic equipment

An intensity probe, Brüel & Kjær, type 4197 [13] with Brüel & Kjær NEXUS conditioning amplifier type 2690 and parametric transducer, a directional loudspeaker HSS-3000 Emitter [14] with HSS-3000 amplifier were used in the reported experiments. The intensity probe was firmly attached to a telescopic tripod and placed at a height of 0.9 m and 1.7 m away from the measured surface. The orientation of the intensity probe with respect to the wall was perpendicular as shown in Fig. 3. The directional loudspeaker was also attached to a tripod and it was placed 4 m away from the wall. The line connecting the centre point of the directional loudspeaker and the middle of the intensity probe was set perpendicular to the wall as shown in Fig. 3. The size of the loudspeaker was 180 mm wide and 300 mm long and 30 mm thick. According to the original theories developed by Westervelt for a parametric acoustic array in the form of a semi-permeable screen [15] and by Lockwood for a parametric acoustic disk [16] the process of generation of the difference wave is primarily confined to the vicinity of the transducer. This means that the amplitude and behaviour of the differential (low-frequency) sound wave away from this transducer is mainly controlled by the source strength density of the primary high-frequency sound field near the transducer's surface (see Eqs. (1), (2) and (4) in Ref. [16]). In the far field, i.e. where our measurements were taken, this differential wave propagates like a spherical wave radiated by a highly directional transducer. Because the source strength density of this wave is proportional to the squared sound pressure in the primary (high-frequency) wave (see Eq. (5) in Ref. [16]), the whole process of audible sound generation by a parametric transducer is biased towards the areas where this primary pressure is particularly high. The primary frequency of the parametric transducer used in this work was 44 kHz. The peak sound pressure of this primary wave was 440 Pa at 0.3 m from the transducer's center. This was sufficient to develop strong non-linear effects causing the emission of the differential wave. The sound pressure in the primary wave reduced to approximately 35 Pa at 4 m away from the transducer. At this position the non-linear effects were relatively weak so that the presence of either a green wall or another surface would be unlikely to affect noticeably the parametric sound generation process in the reported experiments.

For each of the experiments, the intensity probe was shifted left or right and up or down to measure the directivity of the incident and reflected sound waves. The horizontal offset values were: 0; 50; 70; 100; 150; 250; 500 and 750 mm. The vertical offset values were: ±60 mm. The exact locations of the loudspeaker and intensity probe were measured by means of measuring tapes and a set of lasers with level indicators. The choice of these offsets was based on the transducer directivity and typical scattering pattern measured at 1.7 m. The maximum values of the horizontal offset corre-