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Effect of water content on noise attenuation over vegetated roofs: Results from two field studies

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ABSTRACT

Urban traffic noise is mitigated when propagating over vegetated roofs. It is known from results of laboratory measurements that the sound absorption performance of vegetated roofs is affected by its substrate water content. In a previous study on one extensive green roof, a significant decrease of noise attenuation was found when the substrate water content increased, specifically in the frequency range between 250 Hz and 1250 Hz. This work presents new results from long-lasting in-situ experiments on two extensive vegetated roofs in Eindhoven (Netherlands), together with two different methods for obtaining the results. One scenario involves traffic noise and an artificial noise source is used in the other scenario. The sound pressure level differences over the vegetated roofs, substrate water content and meteorological conditions are measured and collected. Although a descending tendency of noise attenuation with the increase of the substrate water content as in previous research can be confirmed, the extent and frequency of this effect vary significantly between the two vegetated roofs, specifically between 400 Hz and 2000 Hz on the Cascade roof and between 800 Hz and 1000 Hz on the Strijp-S roof.

1. Introduction

Urban road traffic noise is one of the most frequently occurring sound sources in the urban environment, except for the natural sounds. It may invoke adverse health effects. A way to reduce the traffic noise is by using noise barriers, which are effective for higher frequencies. However, they are often not accepted from an aesthetic viewpoint in inner-city environments. Urban vegetation such as green roofs is highly important for recovering the ecological balance and providing visually pleasant environments. Moreover, the acoustic potential of the green roofs has been identified as well. Sound waves diffracted over roofs can be absorbed by green roofs and the sound transmission through roof structures can be improved by green roof systems [1–6].

Since the exterior of a non-vegetated roof is most often a rigid material, there is potential in reducing acoustic waves diffracting over buildings. Green roof systems on top of buildings can therefore act as sound absorbers especially for diffracted sound waves between parallel streets and for that purpose, parametric studies have been carried out with green roof systems on top of buildings [7–11], showing that green roof systems are effective for noise mitigation, and therefore creating quiet sides. The vegetation present on green roofs will mainly have an effect at higher frequencies [9,12]. In the case of canyon-to-canyon propagation, these high frequencies are in many cases sufficiently attenuated by the diffraction process itself, in contrast to low frequencies. As a result, the sound field in a shielded zone becomes typically low frequent [13].

The acoustic performance of ground surfaces can be affected significantly by the moisture content of its substrate. It was studied using impedance tube measurements in the laboratory on soils and considerable variations in the acoustic admittance of soils under the influence of small changes (10%–20%) in the degree of pore moisture content was discussed [14–16]. Further impedance tube measurements were carried out on vegetated roof substrates and a decrease of the absorption coefficient was seen as the soil goes from a fully saturated status to dry, especially in the higher frequencies above 1 kHz [17]. Also, Connelly and Hodgson measured the absorption of a vegetated roof under the influence of the compaction and moisture content of six substrate samples in the impedance tube, and found that the average absorption coefficient decreases from 0.71 to 0.35 with the increase of the moisture content from 0% to around 30% volumetric water content [18]. From reverberation room measurements, Yang et al. found a significant decrease in the absorption coefficient of vegetation and soil with the increase of soil moisture content but not noteworthy when the soil is nearly saturated [19]. From an in-situ two-microphone impulse technique of sand, grassland, and soils, Cramond and Don revealed that the relative magnitude of the resonances of the surface impedance

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increases with moisture content levels [20]. Furthermore, from a long-term study on one extensive green roof, Van Renterghem found a significant decrease of noise attenuation when the substrate water content increased, specifically in the frequency range between 250 Hz and 1250 Hz [21].

The aim of this paper is to contribute to the body of evidence of the effect of the water content on sound absorption by extensive vegetated roofs, and by proposing two ways of determining the level difference over vegetated roofs from long-term experiments. The investigation of the effect of the water content on the noise attenuation over two representative vegetated roofs in Eindhoven (Netherlands) is presented based on long-lasting in-situ experiments. In one scenario, traffic noise is used as the noise source for the measurements and an artificial noise source is used in the other scenario. Section 2 starts with an introduction to the experimental setup including the measurement sites and equipment. Section 3 describes the data processing procedures followed to obtain the results. The results of the sound pressure level differences over the vegetated roofs in relation to the substrate water content are presented in Section 4 and conclusions can be found in Section 5.

2. Experimental setup

The investigation of the effect of the moisture content on noise attenuation over vegetated roofs was carried out on two urban vegetated roofs in Eindhoven (Netherlands). The construction and properties of these two vegetated roofs will be first introduced in this section followed by a description of the location and design of the measurement setup. Afterwards, the measurement equipment and sound signals are listed. Finally, the calibration process is explained.

2.1. Vegetated roofs

The measurements have been conducted on two urban extensive vegetated roofs in Eindhoven, the Netherlands. The first one is on the building of a residential apartment at the Strijp-S area of Eindhoven. The measurement roof is on the top floor of a three-storey building at Kastanjelaan as pointed out in Fig. 1 (left). The vegetated roof is built from the following seven main functional layers as illustrated in Fig. 2 (left). On top of the roof construction, there is one layer of waterproof membrane to prevent the water getting into the construction and one protection layer made of polyethersulfone (PES, thickness of 3 mm, 300 g/m^2) to protect the roof membrane against mechanical damage. Then, the protection layer is covered by a drainage layer with a thickness of 40 mm (type DSE 40) made of high-density polyethylene (HSPE). The water storage capacity of this drainage layer is approximately 13.5 l/m^2. The extensive substrate (thickness of 60 mm) is separated from the drainage layer by a filter layer (thickness of 1 mm, 125 g/m^2) made of polyester or polypropylene. The mineral part of the substrate is a mix of lava and pumice. The water storage capacity of the substrate is about 40%. On top of the substrate is the vegetation layer. It contains various types of sedum planted by 16 per square meter. (All the information above about this vegetated roof construction is provided by the green roof supplier 'Van Helvoirt Groenprojecten BV').

The other vegetated roof is located on the Cascade building in the campus of the Eindhoven University of Technology (Fig. 1 Right). The Cascade building was built in 1999 and designed as the laboratory building for the Department of Applied Physics. The vegetated roof is on the top of the lower part of the Cascade building which is around 30 × 32 m^2. However, the vegetation-covered roof only takes 72% of the total roof area and is mainly located in the south part of the roof. Moreover, extra sky windows and HVAC fans can be found within the vegetation-covered roof area. The construction of the vegetated roof on the Cascade building is similar to that on Strijp-S building with the roof construction, waterproof membrane, protection layer, drainage layer (10 mm), filter layer (1 mm), substrate layer (50 mm) and vegetation layer on top (Fig. 2 Right).

2.2. Measurement sites

A measurement setup was first implemented on the vegetated roof of the Strijp-S building during the period between 2014 and 05-19 and 2014-07-28. The setup of the measurement on the Strijp-S building is shown in Fig. 3. From the test building to the building at the other side of the road, there is a 4 m concrete sidewalk, 4 m bicycle way, 2 m vegetated area, 3 m parking area, 4 m northbound auto lane, 7 m planted trees area, 4 m bus lane, 1 m shrub area, 3 m southbound auto lane, 3 m parking area, 2 m bicycle way and 1 m sidewalk. The horizontal distance between the center of the traffic lanes on Kastanjelaan and the edge of the vegetated roof (close to the street) is about 22.5 m. The two measurement microphones are positioned at the two edges of the test building, 12.25 m apart in the west-east direction. One moisture meter is inserted in the substrate in-between the two microphones. The microphones and the moisture meter are fixed on their positions throughout the experiment. Moreover, the meteorological conditions for the measurement site are collected from the Koninklijk Nederlands Meteorologisch Instituut (KNMI) database at Eindhoven (51° 27 ′N 05° 23′ OL, about 9.5 km away from the measurement site).

The other measurement was conducted on the Cascade building (Fig. 4) from 2017 to 07-14 to 2018-02-06. As little traffic noise arrives at the roof, an artificial sound signal is played by a loudspeaker positioned on the roof, together with two microphones.

Since the largest absorption effect happens when the sound propagates close to the roof surface, the microphones and speaker are placed above the roof surface with a height of 0.05 m. The speaker is positioned at 4.7 m away from the edge of the roof on the east, and the two microphones are placed 0.6 m and 5.7 m westwards from the speaker

Fig. 1. Images of the investigated vegetated roofs. Left) Strijp-S vegetated roof; Right) Cascade vegetated roof.