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In-situ measurements of sound propagating over extensive green roofs

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ABSTRACT

In this study, in-situ measurements of sound propagating over flat, extensive green roofs are presented for 5 cases. Measurements were performed just before and just after the placement of the green roof (under dry conditions) with an identical source-receiver configuration in both situations, allowing a direct estimate of the acoustical effect. Situations involving a single and double diffraction over the green roof were considered, for substrate thicknesses ranging from 20–30 mm to 180 mm, and for vegetation cover ranging from absence to 100%. The green roof acoustic effect was analyzed for propagation path lengths interacting with the roofs ranging from 2.5 m to 25 m. Measurements show that green roofs might lead to consistent and significant sound reduction at locations where only diffracted sound waves arrive relative to common, non-vegetated roofs. A single diffraction case with an acoustic green roof improvement exceeding 10 dB was found for sound frequencies between 400 Hz and 1250 Hz, although the green roof interaction path length was only 4.5 m. For less shielded receivers, a change in interference pattern might be observed, leading to positive or negative effects, relative to a non-vegetated roof top. For the double diffraction cases the green roof improvement is less frequency-dependent and a case with positive effects up to 10 dB was found.

1. Introduction

The ecological and economic advantages of green roofs have been well-recognized. Scientific studies focus mainly on thermal insulation, energy consumption of buildings and reduction of urban heat island effects [1–8], rainwater runoff management [9–12], air quality improvement and increased carbon dioxide uptake [13,14], increasing biodiversity in an urban environment [15–17], and economic and environmental life cycle assessment [18–21].

Only very recently, scientific research to the acoustical effects of vegetated roof tops is conducted. Basically, sound can be reduced by a green roof in two ways, namely by providing increased insulation of the roof system and by absorption of sound waves diffracting over roofs.

A straightforward effect is the decreased sound propagation through the roof system to the inside of the building. This effect was studied experimentally under controlled conditions by means of a small box equipped with a semi-extensive green roof in Ref. [22]. This application of green roofs is rather limited. The presence of noise sources above roof level is uncommon, unless air traffic is considered. Nevertheless, only in a very dense building setup positive effects can be expected, since in such situations sound is nearly normal incident on the roof during a complete passage. For detached buildings, the effect of a green roof on noise exposure from overflying air traffic is expected to be limited when considering time-integrated sound levels.

The material properties of objects over which sound diffracts play an important role. Hadden and Pierce proposed an accurate analytical solution for sound diffraction near wedges [23]. This method is often referred as the four-ray diffraction model since 4 terms appear in their analytical solution. Three of these terms are associated with the absorption characteristics of the faces constituting the diffracting object. One term uses the properties of the face at the source side, another term the properties of the face at the receiver side, and a third term is influenced by both faces. Calculations in Ref. [24] show a large decrease in sound pressure level at a partly absorbing right angle, relative to a fully rigid one. With increasing distance between the diffracting edge and receiver, such effects become more pronounced. Furthermore, when receivers are located close to the surface, or in case of double diffraction (e.g. sound propagation over a rectangular building), the angle of incidence is near parallel to the absorbing material. As a result, the absorption of sound waves increases significantly [25].

The typical green roof substrates have interesting sound absorbing properties. Growing mediums used in green roofs are highly-porous, and allow acoustic waves to enter the medium,

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which is a necessary property of a sound absorbing material. Due to the large number of interactions between the waves and the solid phase of the substrate attenuation occurs.

These theoretical considerations are consistent with the numerical calculations in Refs. [26,27], showing the high potential of green roofs in reducing diffracting sound waves over it, compared to (acoustically) rigid roofs, for various building and roof types. The importance of parameters like the surface area covered with green roof substrate, the substrate depth of both intensive and extensive green roofs, and uniformity of the calculated effects along the shielded façades were studied.

Although the presence of an obstacle like a building or house induces a high degree of shielding, sound levels can still be high at shielded locations near street canyons (with dense road traffic), due to the large number of reflections in between the building façades forming the street. Such street canyons are however common in many city centres. Furthermore, the presence of a silent courtyard or façade was identified as important based on large scale noise annoyance surveys [28,29]. A quiet side allows people to organize their homes and to place noise-sensitive rooms at the silent façade, or to benefit from the mental restoration found in silent courtyards in an otherwise noisy environment.

However, experimental data with relation to sound propagation over green roofs is lacking. The numerical simulations in Refs. [26,27], although using a state-of-the-art full-wave numerical technique, involved some idealizations. Firstly, only a homogeneous growing substrate was modeled. Secondly, the parameters to describe the acoustic properties of the granular substrate in the simulations were derived from literature reports of equivalent materials.

Good green roof practice, on the other hand, involves various layers, each with a specific purpose. A typical build-up is as follows. A root barrier membrane is needed if the roof finishing might be penetrable by plant roots. Next, a drainage layer is needed to evacuate excess water. This could be a gravel-like material or a profiled synthetic fabric. The latter often contains small water reservoirs in order to allow water to evaporate and penetrate the substrate in periods of drought. Another advantage of such a profiling is to prevent acidification of the substrate by easily allowing air to enter from below. Next, a geo-textile or filter membrane is placed, mainly to prevent substrate loss. This layer is topped by the granular growing medium. The thickness of the substrate depends on the plant needs and is also limited in practice by the weight allowed by the roof construction (taking into account periods of water saturation in the green roof layers). A mineral, highly water absorbing fabric like rock-wool might be placed just below the substrate to largely increase water retention. Finally, a vegetation layer is present. Depending on the species choice and on location-dependent parameters (like roof construction and climate), adaptations to the succession of these layers can be made and appropriate layer thicknesses should be chosen. It is clear that the acoustical effects of such choices might strongly influence the sound absorption property of the roof system as a whole.

In this study, in-situ measurements of the effect of extensive green roofs are presented. It is intended to show what can be expected from current green roof practice in Flanders (Belgium), for sound diffracting over it, for various building configurations. Measurements were performed just before and after placement of the green roof, with an identical source-receiver configuration in both situations. In this way, the green roof effect can be directly estimated, since the only difference between the two measurements was the presence of the green roof.

The paper is organized as follows. In Section 2, the measurement methodology and instrumentation is described. In Section 3, the different cases are presented. In Section 4, results are discussed and finally conclusions are drawn in Section 5.

2. Measurement methodology and instrumentation

In this study, portable and battery-driven equipment was used. In this way, the operator has full flexibility to choose source and receiver locations at the measurement sites.

An alarm gun (Bruni mod. 92, with 8 mm blanks) was used as acoustic source. The use of such a noise source is common in room acoustic applications, and is sometimes used in (outdoor) sound propagation experiments. A main advantage of such a device is the emission of high sound levels which makes a shot easily identifiable even at locations with high background noise levels. Furthermore, an acoustic pulse is produced which contains a wide range of sound frequencies. An alarm gun is also a good approximation of a point source, especially at lower frequencies. Lastly, it is highly mobile and independent of external power.

The reproducibility of successive shots produced by the gun was checked in a full anechoic chamber. Five shots were released at 4 m from the microphone. The averaged recorded spectrum (1/3 octave bands) is shown in Fig. 1. At 100 Hz, a sound pressure level of 73 dB was measured. At 1 kHz the maximum level in the spectrum is obtained, exceeding 100 dB. Up to 10 kHz, the levels stay above 90 dB. At low frequencies, levels are rather limited. Nevertheless, it is expected that these frequencies are only affected to a limited degree by a green roof substrate. Furthermore, these long wavelengths are shielded to a limited degree only, yielding sufficiently high levels after being diffracted. The size of the error bars drawn at each frequency equals 2 times the standard deviation. Both at low (<100 Hz) and high frequencies (>2500 Hz), the standard deviations are near 2 dB. For the intermediate frequencies, this value is between 0.5 dB and 1 dB. It can therefore be concluded that the reproducibility at each 1/3 octave band is sufficient by emitting a series of 5 shots.

The measurements were performed with a ½″ electret microphone (type MK 250 B, Microtech Gefell) with a sensitivity of 44 mV/Pa, connected to a pre-amplifier (type SV 12, Svantek). The microphone capsule has a flat frequency response over the full audible frequency region, and deviations are less than 1 dB up to 15 kHz for normal incident sound. The saturation level exceeds 140 dB (at 1 kHz) and is sufficiently high for the envisaged application.

The logging of the measurements was done with a Svantek 959 handheld device. Results were logged as 1/3 octave bands every 10 ms. Before each measurement, the full measurement chain was

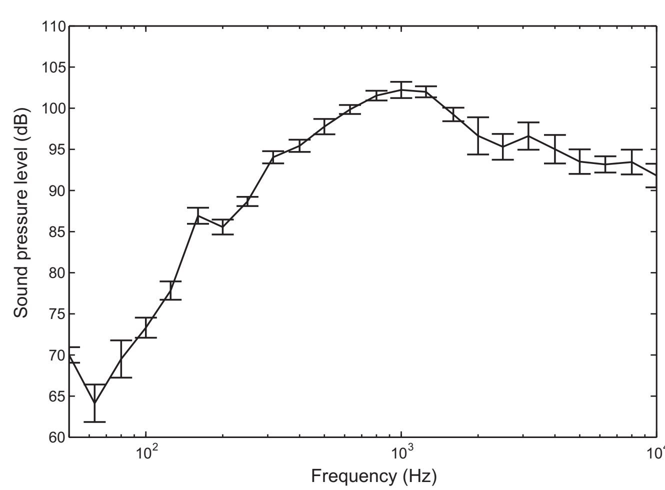

Fig. 1. Sound level spectrum in 1/3 octave bands produced by the alarm gun in the anechoic chamber (at a distance of 4 m). The error bars at each frequency are based on 5 repetitions and have a length of 2 times the standard deviation.