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Green roofs to enhance quiet sides

Timothy Van Renterghem and Dick Botteldooren

University Ghent - Department Information Technology, Sint-Pietersnieuwstraat 41, 9000
Gent, Belgium

timothy.van.renterghem@intec.ugent.be

In this paper, the finite-difference time-domain method is used to study sound propagation over a green roof in an urban situation. Sound propagation between adjacent city canyons is considered, and the focus is on the reduction of the sound pressure level in the non-exposed canyon due to the presence of a vegetated (green) roof. Numerical calculations have been conducted for both intensive and extensive green roofs, showing that an important reduction of the sound pressure level in the shielded canyon can be achieved, compared to a rigid roof. In case of an extensive green roof, there is a strong dependence on the substrate layer thickness; a maximum reduction of 10 dB at the octave band of 1000 Hz was found. A good overall efficiency is observed near the maximum layer thickness as found in practice for this type of green roof. For intensive green roofs, the influence of the substrate layer thickness is limited.

1 Introduction

The exterior of the roofs of houses and buildings is most often made of rigid materials. This means that there is important potential in reducing acoustic waves diffracting over roofs.

A vegetated roof top (green roof) is a good candidate in this respect, since both extensive and intensive green roofs have porous substrates. This means that sound waves may enter the growing medium, interact with the substrate particles, and will be (partly) absorbed.

Green roofs have a large number of economic and ecological benefits, besides its potential to reduced noise. These beneficial effects range from a cut-down in energy costs [1] to a reduction in flooding risks in urbanized areas [2].

This study describes some aspects of a numerical study to the effect of the presence of a green roof in an idealized street canyon configuration.

2 Sound propagation model

The following equations describe sound propagation in (free) air:

$$\nabla \cdot p + \rho_0 \frac{\partial \mathbf{v}}{\partial t} = \mathbf{0}, \quad (1)$$

$$\frac{\partial p}{\partial t} + \rho_0 c_0^2 \nabla \cdot \mathbf{v} = 0. \quad (2)$$

In the linear equations above, p is the acoustic pressure, \mathbf{v} is the particle velocity, ρ_0 is the mass density of air, c_0 is the adiabatic sound speed, and t denotes time. A homogeneous and still propagation medium is assumed. Viscosity, thermal conductivity, molecular relaxation, and gravity are neglected.

Sound propagation in a porous (rigid-frame) medium can be described by the Zwikker and Kosten phenomenological model [3]:

$$\nabla \cdot p + \frac{\rho_0 k_s}{\varphi} \frac{\partial \mathbf{v}}{\partial t} + R \mathbf{v} = \mathbf{0}, \quad (3)$$

$$\frac{\partial p}{\partial t} + \frac{\rho_0}{\varphi} \frac{c_0^2}{k_s} \nabla \cdot \mathbf{v} = 0. \quad (4)$$

In the equations above, R is the flow resistivity of the ground medium, φ its porosity and k_s the structure factor. A

lowest-order, explicit FDTD scheme is used to solve these equations. Such a compact scheme allows an easy inclusion of complicated obstacles and easy handling near interfaces between different propagation media (like the air-substrate interface in the current application). Since the simulation space in outdoor sound propagation applications is usually very large, explicit schemes are interesting because they scale very well.

In a medium at rest, a staggered spatial grid and staggered time-discretisation results in a very efficient numerical scheme [4]. Central difference approximations of the spatial and temporal derivatives in such a scheme result in second-order accuracy [4]. The scheme is also very efficient in memory usage. Staggered-in-time allows for in-place computation: the new values of the acoustic pressure and acoustic velocity replace the old ones in computer memory. Since memory use is often the bottleneck in FDTD simulations, this is an important feature.

The ground medium is included in the calculation domain, and allows taking into account the effect of substrate layer thickness. It will be shown in this study that this is an important parameter, and justifies the need for such a highly detailed numerical model.

In the current application, we are interested in octave band sound pressure levels. The use of a time-domain model is advantageous in this respect. With a single simulation, the response over a wide range of frequencies can be calculated, when working with a pulse-like source and when applying a Fourier transform afterwards. In a frequency-domain technique, on the other hand, a large number of separate calculations are needed (for individual frequencies) to achieve convergence when constituting octave bands.

3 Numerical accuracy near ground-air interface

A spatial discretisation of 10 computational cells per wavelength results in accurate simulations in (free) air. A larger resolution is however needed near the air-substrate interface and in the porous medium, to capture the rapid decay of sound pressure. With increasing impedance of the substrate medium, a finer grid is needed.

The grid resolution required for accurately modeling reflection on the ground was investigated in a numerical test. A plane wave normal incident on a number of ground cells was simulated. The complex surface impedance of the soil was calculated, based on the incident and ground-reflected pulse. In Figs. 1 and 2, a comparison is made between the acoustic surface impedance obtained by the FDTD simulation with respectively a 2-cm and a 1-cm grid

step, and the analytical impedance (5), derived from Eqs. (3) and (4):

$$Z = \sqrt{\frac{R}{\rho\omega\varphi} j + \frac{k_s}{\varphi^2}}. \quad (5)$$

Based on this analysis, a grid step of 2 cm was not sufficient, in particular because the real part of the impedance deviates significantly from the analytical solution. This error increases with frequency. The imaginary part of the ground impedance corresponds very well to the analytical solution in both discretisations.

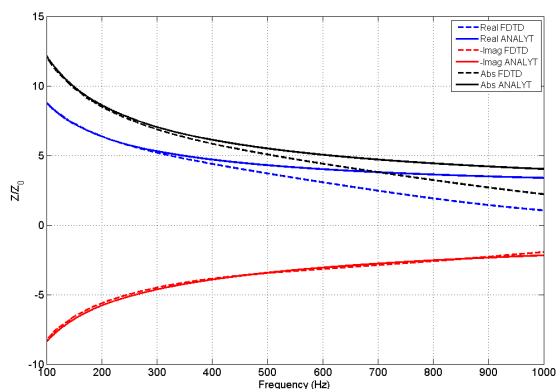


Fig.1 Comparison between the analytical and numerical impedance of the substrate medium, for a 2-cm grid step ($R=50 \text{ kPa s m}^{-2}$, $\varphi=0.45$, and $k_s=1.35$).

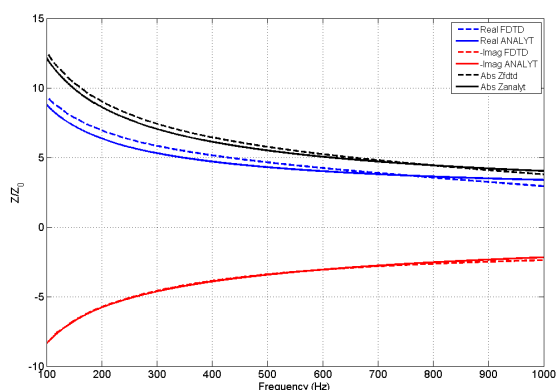


Fig.2 Same as Fig.1, but now for a 1-cm grid step.

4 Numerical results and discussion

The numerical calculations are performed in an idealized street canyon configuration. Sound propagation from a source canyon (with dimensions of 10 m on 10m) to an identical receiver canyon is considered. Both canyons are separated by a 10 m on 10 m building with a flat roof. All horizontal planes are rigid (except when there is a green roof). The façades are fully specular reflecting, and have a reflection coefficient of 80 % (bricks).

Both extensive and intensive green roofs significantly reduce the sound levels in the non-exposed canyon. At low frequencies, effects are minimal since the substrate impedance is large. For a typical intensive green roof, more than 6 dB is gained at the octave band of 1000 Hz, relative to a fully rigid roof.

In Fig. 3, the influence of substrate depth for an extensive green roof is shown. The average decrease of the octave band sound pressure level, relative to a fully rigid roof, over a receiver line at a height of 2 m in the non-exposed canyon, is shown. This green roof effect was found to be insensitive of the exact location in the non-exposed canyon. The positive effect of the presence of a green roof starts from about 30 cm at 125 Hz, and from 15 cm at 250 Hz. An optimal layer thickness is observed, which shifts towards smaller values with increasing octave band centre frequency. For 1000 Hz, this optimum is near 10 cm, and results in a decrease of 10 dB compared to a fully rigid roof. At 500 Hz, this optimum is observed for a layer thickness near 20 cm, leading to 6 dB reduction. With increasing frequency, this minimum becomes more pronounced.

An intensive green roof has a minimum layer thickness of about 20 cm. The influence of thicker layers was found to be very small. The thickness of an extensive green roof amounts from a few centimetres up to 15-20 cm in practice. It can therefore be concluded that an extensive green roof can be tuned in this range to achieve sound reduction based on the source spectrum.

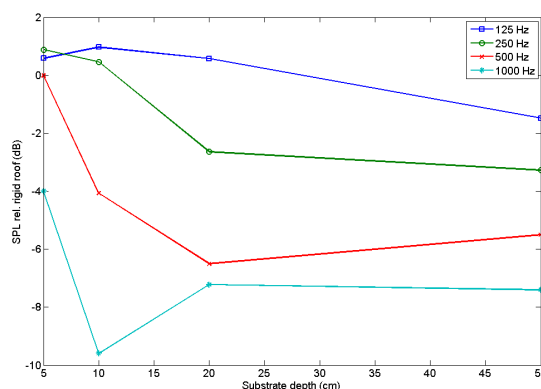


Fig.3 Effect of substrate depth on the sound pressure level in the non-exposed canyon, relative to a fully rigid roof. An extensive green roof ($R=10 \text{ kPa s m}^{-2}$, $\varphi=0.40$, and $k_s=1.5$) is simulated, which takes 90 % of the roof surface.

References

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