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Reducing the acoustical façade load from road traffic with green roofs

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ABSTRACT

Noise annoyance by road traffic is a major issue in urbanized regions. In this study, the influence of a green roof on the façade noise load was investigated numerically for road traffic at close distance. Consistent positive effects of the presence of a green roof are observed at non-directly exposed (parts of) façades. A sufficient green roof area is needed to obtain significant reductions in total A-weighted road traffic noise level. With increasing traffic speed, the green roof effect increases for light vehicles. In case of heavy vehicles, this dependence is less strong. In a street canyon situation, the façade load in the non-exposed canyon is largely influenced by both the roof slope and the presence of a green roof. A flat roof generally results in the best average shielding. A green roof is especially interesting in case of a saddle-backed roof. With a good choice of green roof parameters, the shielding of a flat green roof can be approached.

1. Introduction

Noise annoyance by road traffic in urbanized regions is a major issue. It is estimated that about 44% of the population of the European Union (in the year 2000) was exposed to road traffic noise levels (near their houses) above the World Health Organization's threshold for onset of negative health effects [1]. Although important improvements have been made during the last decades by continued tire engineering, by producing more silent engines and by the development of new types of road surface top layers, the sound pressure levels are most often still too high for dwellings at limited distance from roads.

The propagation path between the source location and receivers can be exploited to further reduce noise levels. A noise barrier for example is an important and adequate measure to reduce sound pressure levels near highways, but its applicability in city centers and even in suburban areas is limited.

The acoustical façade load, i.e. the sound pressure level at the outside of the building, and the façade insulation are key to estimate indoor sound pressure levels. Although façade insulation can be a very successful measure for solving particular sleep disturbance and noise annoyance problems, it has been shown that in general noise annoyance is not reduced by insulation as much as could be expected on the basis of levels [2]. The simple explanation for this is that people open windows and spend time outside their dwelling. Thus, measures for reducing façade load such as the roof coverage (with focus on greening) and roof type studied in this paper remain very attractive complements.

Green roofs (or vegetated roof tops) have important noise reducing properties, besides a large number of economic and ecological advantages (e.g. Refs. [3–7]). A straightforward acoustical application of green roofs is the increased sound insulation of the roof system. This could lead, depending on the geometry of the building, to large reductions of indoor noise levels for example during a plane fly-over. In this study, it will be shown that there are also interesting applications for reducing exposure to road traffic noise and noise from other sources situated at low altitude. Indeed, since the exterior of a non-vegetated roof is most often a rigid material (acoustically reflecting to a large extent), there is potential in reducing acoustic waves diffracting over buildings or parts of buildings. The typical substrates used in both extensive and intensive green roofs are porous and thus allow sound to enter the growing mediums. Because of the large number of interactions between sound and substrate particles, attenuation occurs. Moreover, the modified sound waves can destructively interfere at locations where quietness is desired.

Extensive green roofs only need a thin layer of soil substitute i.e. a granular substrate. They support low-growing plants like Sedum species and grasses. Intensive green roofs, on the other hand, require larger soil depths and may allow growing shrubs or even trees. They typically contain uncompacted (loose) earth. Both types of substrates can be categorized as acoustically soft mediums.

In a previous study [8], different aspects of numerical modelling of diffracting sound waves over green roofs were considered. The influence of substrate depth of extensive and intensive green roofs was studied in detail.

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In this work, an assessment is made of the noise reducing capabilities of green roofs for overall A-weighted traffic noise at building façades. In particular, road traffic at short distance from the building façade is considered. Numerical calculations will be performed for two geometries, more precisely a terrace covered with green and a green roof in a street canyon configuration. In both cases, the sound pressure level at the façades in the presence of green roofs is compared to exactly the same geometry, but with the green roof replaced by a fully rigid roof.

This paper is organized as follows. Section 2 briefly describes the numerical sound propagation model. In Section 3, the road traffic source model that will be used for the numerical calculations is discussed. The geometry of the two types of building configurations considered in this study is described in Section 4. In Section 5, the numerical results are shown and discussed. In Section 6, conclusions are drawn.

2. Sound propagation model

The following equations describe sound propagation in air:

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

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

In the linear Eqs. (1) and (2), p is the acoustic pressure, $\boldsymbol{v}$ 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 [9]:

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

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

In Eqs. (3) and (4), R is the flow resistivity of the porous medium, φ its porosity and k_s the structure factor. Appropriate substrate parameters for both intensive and extensive green roofs were found by means of a literature study [8].

The finite-difference time-domain (FDTD) method is used to solve Eqs. (1)–(4). All important wave aspects like multiple reflections, multiple diffractions, and the interaction between sound and the green roof substrate are accurately modeled. The staggered-in-time and staggered-in-space discretisation approach is chosen [10]. The advantages of this numerical scheme were described elsewhere [11]. The FDTD method has become a reference solution in non-trivial applications [12]. This numerical method has been validated thoroughly by comparison with measurements, analytical solutions and other numerical methods, over a wide range of acoustical applications [13–16].

The FDTD method is a volume-discretisation technique and is therefore computationally costly. Simulations are limited to 2D, implying an infinitely long (coherent) line source and buildings having a constant cross-section. Although road traffic is more accurately modeled as an incoherent line source (i.e. the phase difference between the different point sources forming the line source is random), it was shown that source type is not important when comparing the effect of roof coverage [8].

On the other hand, the use of a time-domain model is advantageous. 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. Most road traffic source power models are available in 1/3 octave bands. To obtain accurate propagation data, at least 10 frequencies per 1/3 octave band need to be obtained. A frequency-domain technique requires a new calculation for each of these frequencies while the time-domain approach produces the required spectrum at once.

3. Road traffic source spectrum

The Harmonoise/Imagine road traffic source model is used. This is a state-of-the-art model, based on numerous measurements and outcomes of national and international research projects. A summary of this calculation method can be found in Ref. [17]. According to this model, each vehicle can be represented by two (incoherent) omni-directional point sources. The first source is placed at a height of 0.01 m above the road surface, and the second one at a height of 0.30 m or 0.75 m, respectively, for light vehicles (e.g. person's cars) and heavy traffic. The first source point is associated with rolling noise and the second one with engine noise. 80% of the rolling noise source power model given by the Harmonoise model should be attributed to the lowest point source and 20% to the highest source point. The engine source power, on the other hand, is assigned for 80% to the source at 0.30 m (or 0.75 m), and for 20% to the source at 0.01 m. The source powers depend on the sound frequency, traffic speed and vehicle type.

Default values of the basic model are assumed for the calculations in this study. This implies that the vehicles are driving at constant speed on a dense asphalt concrete road top layer, and the air temperature is 20 °C.

4. Building configurations studied

The acoustical effect of the presence of a green roof was studied in two situations. In the first configuration, the façade under study is partly in the acoustic shadow zone, while in the second configuration, the (full) façade is only indirectly exposed.

The first configuration is shown in Fig. 1. A green roof is present on a terrace, which is an extension of the main building. Façades A and B constitute of a brick-wall and each have a window of 2 m high, starting from the floor levels. Façade A has a height of 3 m, while the maximum building height equals 7.5 m. Terraces with lengths of $D_2 = 5$ m and $D_2 = 10$ m are considered. The road is located at, respectively, $D_1 = 10$ m and $D_1 = 5$ m from façade A. These configurations will be indicated as the 5-m and 10-m building extensions, respectively. The sound pressure levels are evaluated very close to façade B (at 0.5 cm).

The second configuration, depicted in Fig. 2, is an idealized street canyon, which is common in a dense, urban setting as can be found in many (old) European cities. The street canyons have a width of 10 m and a width-height ratio of 1 in case of a flat roof. The road traffic source is located in the street on the left side of the middle building and the influence of the green roof on the acoustical load at façade C (at 0.5 cm) is considered. The source is located at 4 m from façade A. Given the large number of reflections in the street canyons, the exact location of a source near ground level was shown to be of minor importance [18]. The roof slopes α considered were 0° (flat roof), 15°, 30°, and 45°. To allow for a fair comparison, the volume of the buildings is kept the same when varying roof slope. This leads to façade heights H of 10 m, 9.33 m, 8.56 m, and 7.5 m, respectively. All building façades consist of bricks and are fully specularly reflecting.

In both configurations, all horizontal surfaces and roofs are rigid, except at the locations where a green roof is present. Both extensive and intensive green roofs are considered. Sound propagation in the substrate layer itself is explicitly modeled. Based on previous optimizations of substrate depths [8], and taking into account