Street Canyons and Quiet Side: Comparing FDTD Simulation and Engineering Models

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Introduction

Ongoing urban soundscape research has pointed out the importance of having access to a quiet side of the dwelling for the perceived quality of the urban living environment. In an urban setting, a quiet side originates from the strong screening by nearby uninterrupted rows of houses. The source of noise is primarily the traffic that may be surrounded by a street canyon.

Different models can be employed to quantify the quiet side. Finite-difference time-domain (FDTD) discretization of the Linearized Euler equations (LEE) is well suited to simulate sound propagation in such a complex environment. The demands on computing power however limit the applicability for modeling large parts of cities. Engineering models based on ray tracing and image sources are better suited to handle these large areas filled with 3D reflecting and screening objects. Because they are in essence high-frequency approximations, their description of diffraction and other wave phenomena at lower frequencies is less accurate.

This paper estimates the accuracy of engineering models with respect to the FDTD approximation of LEE for the particular situation where the source is in a street canyon and sound levels at the quiet side are of interest.

Models

FDTD

The FDTD method that is used as the reference model in this work, is a full-wave numerical simulation technique based on the linearized Euler equations (LEE). The model as described in [1][2] can account for the most important interactions between sound and wind outdoors. It uses a static background flow, calculated with standard CFD software. Synthetic turbulence (turbule model) is added if required. Multiple reflections and diffractions, diffuse reflection, scattering from irregular objects, all in combination with the inhomogeneous propagation medium are automatically included.

Engineering models based on ray tracing

Engineering models such as ISO-9613 [4] combine simplified semi-empirical description of wave effects such as diffraction and ground interference with a ray tracing technique for including reflections. In the urban area under consideration multiple reflection is of utmost importance. Therefore, Bass2.5, a very efficient implementation based on object precise polygonal beam tracing is used in addition to the commercial general purpose software IMMI[1] as an incarnation of ISO-9613. Both do not include meteorological effects explicitly, but assume moderate downward refraction.

Other Models

Extensions to classical ray tracing make the technique more suitable for the problem under study. These extensions include modeling background flow by using bent rays and placing secondary sources emanating diffracted rays on wedges to account for diffraction [3]. These extensions come at a severe cost, making the approach less attractive. The parabolic equation can readily be extended to account for background flow [6], and is often used for simulation outdoor propagation. The low aperture angle and the one-way propagation limit the use of this technique in a typical street canyon where the angle with the nearest wall top is often more than 65°. Boundary element methods are full wave approaches thus perfectly able to handle diffraction. In there basic form they are less suited for including meteorological effects because a Greens function can only be derived for very simple wind and temperature profiles. The related equivalent sources model proposed in [8], splits the problem in a wind free street canyon and a layer including turbulent scattering above the houses.

Comparison

Setup

The prototype urban situation used in this comparison is shown in figure 1.

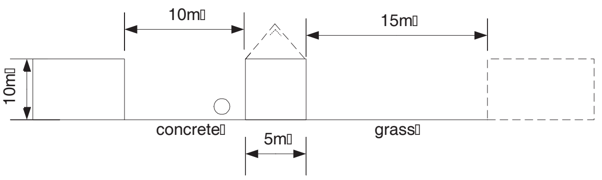

Figure 1: Street canyon

The street canyon is bounded by concrete walls with a relative impedance $Z_{concrete} = 13 + j0$ and is $10m$ wide and high. The roof on the right hand side is either a flat roof or a saddle roof with the same impedance. To simulate reflection from a natural soil in the FDTD model, the propagation in the ground is included. The sound propagation equations are adapted based on the physical parameters of the soil. The model of Zwikker and Kosten [5] can be used to approximate the frequency-impedance behavior of a large number of soils. The parameters used for

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[1] IMMI 5.1, Wölfel Meßsysteme Software

the backyard soil are $R = 300kPas/m^2$, $k_s = 3, \phi = 0.3$. The engineering model assumes a *soft ground* as backyard.

To compare models, an area of interest in the backyard spanning the whole $15m$ and a height from $0.3m$ up to $2m$ was selected. Differences in excess attenuation compared to free field for octave bands from $63Hz$ to $1kHz$ are analyzed statistically. In this written report, only mean values are reported.

Simulation results

Insertion loss: Figure 2 shows the mean attenuation for four different simulation: FDTD, IMMI, Bass2.5 and FDTD in wind, for the case with a flat roof and no house behind the backyard.

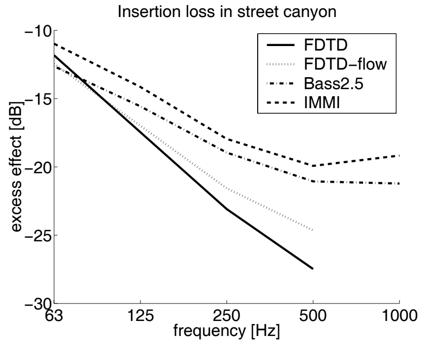

Figure 2: Excess effect in backyard for different models.

The results show that the engineering models predict less screening than FDTD for high frequencies and this is mainly caused by the explicit limit on the magnitude of screening that these models include. When refraction by background flow is included in the FDTD simulation, a better agreement is found. An additional one or two dB increase is found at $1000Hz$ if strong turbulence is added.

Shape sensitivity: When the houses at one side of the street have a saddle roof (see figure 1), the FDTD method predicts 10 dB more excess attenuation while the engineering models only predict 2 dB. Using more advanced screen diffraction formulas may solve this problem, at least for frequencies above 100 Hz [7]. The influence of the roughness of the canyon walls was tested by applying a random distribution of blocks of 4 cm on 50 % of the surface of the walls. FDTD simulation resulted in a decrease of backyard noise levels of 5 dB for the 500 Hz octave band and about 1.5 dB at lower frequencies.

Maximum number of reflections considered: For the street canyon and quiet backyard problem the maximum number of reflections considered in the engineering model is expected to have a strong influence since the path length of consecutive reflections grows slowly and screening gradually reduces with reflection order. Figure 3 shows that once 6 reflections are taken into account, the change in excess attenuation with increasing number of reflections considered is less than 0.5 dB.

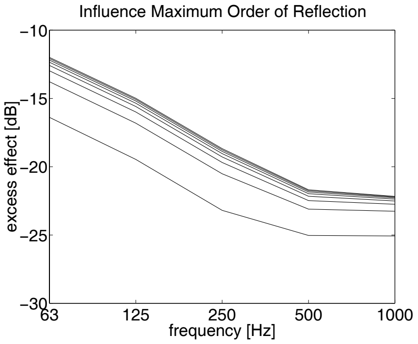

Figure 3: Excess effect for maximum number of reflections between 0 to 14 (increments of 2)

Conclusion

This paper focusses on the problem of quantifying noise levels in a quiet backyard in a typical urban setting where the source is in a so called street canyon. The computational intensive but more accurate FDTD simulation of the LEE was compared with a simulation based on the ISO-9613 engineering approach. From the numerical experiments presented, it can be concluded that the engineering model approximates noise levels in the backyard quite good, if anything slightly overestimating them. This is not surprising since these models tend to consider unfavorable meteorological conditions. However FDTD simulations suggest a large sensitivity to the shape of the roof and the roughness of the street canyon walls. These factors should be added to future, improved engineering models.

References

[1] The finite-difference time-domain method for simulation of sound propagation in a moving medium. T. Van Renterghem, PhD thesis, Ghent University, 2003

[2] Sound diffraction around screens and wedges for arbitrary point source locations. T. Van Renterghem and D. Botteldooren Acta Acustica united with Acustica **89**(5) (2003), 764–778

[3] Sound diffraction around screens and wedges for arbitrary point source locations. W.J. Hadden, Jr. and A. D. Pierce JASA **69**(5) (1981), 1266–1276

[4] ISO 9613-2, Acoustics-Attenuation of sound during propagation outdoors – Part 2.

[5] Sound absorbing materials. C. Zwikker, C. W. Kosten, Elsevier, 1949

[6] Computational Atmospheric Acoustics. E. Salomons, Kluwer Academic Publishers, 2002

[7] Comprehensive Outdoor Sound Propagation Model. Propagation in Atmosphere without Significant Refraction. B. Plovsing, J. Kragh. DELTA

[8] Including Turbulence and Absorption Effects in City Canyon Calculations. M. Ögren, J. Forssén and W. Kropp 10th ICSV, Stockholm 2003, 1389–1396