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An efficient model for background noise mapping

W.Wei, T. Van Renterghem, D. Botteldooren
Department of Information Technology, Ghent University, Gent, Belgium

M. Hornikx, J. Forssén
Chalmers University of Technology, Applied Acoustics, Sweden

E. Salomons
Institute of Applied Physics, TNO, Delft, Netherlands

M. Ögren
Department of Environment and Traffic Analysis, VTI, Gothenburg, Sweden

Summary

It has been shown that inhabitants of dwellings exposed to high noise levels benefit from having access to a quiet side. Therefore the European Environmental Noise Directive allows member states to include the presence of a quiet side in their reports. However, current practice applications of noise mapping methods usually underestimate the noise level at the shielded façade when the most important contribution is sound propagation over the rooftop. Multiple reflections from opposite façades in street canyons are not sufficiently taken into account. In addition, sources at distance much larger than normally taken into account in noise maps might in some cases still contribute significantly. Since one of the main reasons for this poor approximation is computational burden, an efficient engineering model is proposed, which considers multiple reflections and turbulence scattering. The model uses an analytical function of a complexity comparable to ISO 9613 formula for noise barriers that is fitted to an extensive set of FDTD (finite difference time domain) simulations of canyon-to-canyon sound propagation. This model allows calculating the background noise in the shielded areas of a city, which could then be used to refine noise mapping calculations.

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1. Introduction

A widely accepted idea is that inhabitants of dwellings exposed to high noise levels can benefit from having access to a quiet side [1, 2, 3]. Although the Environmental Noise Directive proposes a level difference between most exposed and shielded facade of 20 dB, a good definition is however lacking [4]. In typical European cities, many enclosed residential courtyards or green parks could provide such a quiet area. To adequately assess the effect, a good estimation of noise levels in shielded areas is needed. However, current practice applications of noise mapping methods usually underestimate the noise level at the shielded façade.

The equivalent source method, PSTD and FDTD have been used previously to predict shielding between city canyons [5, 6, 7]. For propagation outside the source canyon, the flat city model assumes that the propagation can be represented as a coupling between the source canyon and receiver canyon combined with propagation over an essentially flat city. Although this model overestimates about 6 to 10 dB in the shielding canyons, a correction factor derived from the measurement can improve it considerably. If the city tops are supposed to be flat, a serial of simplified equivalent sources at the roof height can calculate the propagation in an urban area [8, 9].

However, these detailed numerical models cannot be used for mapping the background noise level of a whole city. Hence the need for a more specific engineering approach rises. Both the direct and reflected sound can diffract over the roof top and arrive at the shielded yard. The multiple reflected part is usually not sufficiently taken into account in currently available models and turbulent scattering could be important at such shielded locations as well [10, 11]. In addition, sources at distance much larger than normally taken into account in noise maps might in some cases, such as the downward refraction or hilly terrain, still contribute significantly. By multiple reflections,

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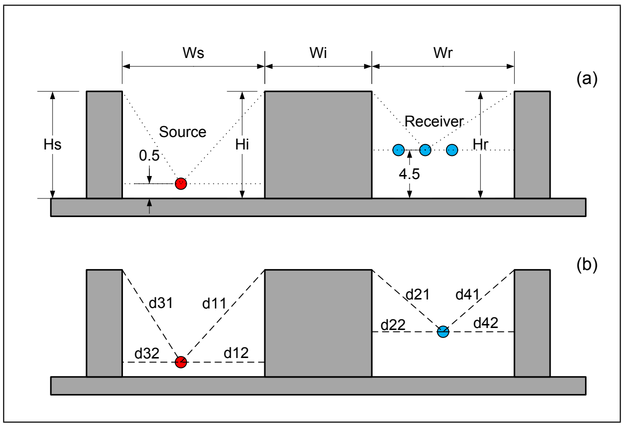

Figure 1. A typical simulation configuration, where H_s and H_r are the building height of source and receiver canyon; H_i is the height of the intermediate building; W_s, W_i and W_r are the width of the source canyon, the intermediate building and the receiver canyon.

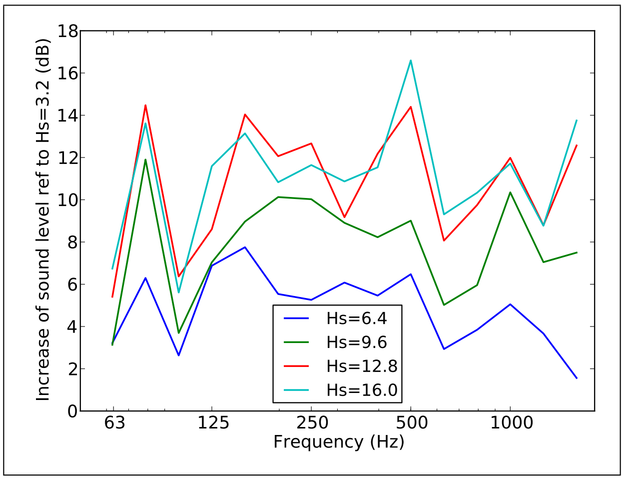

Figure 2. Source canyon effect as a function of frequencies, observed at the center of the receiver canyon.

sound is redistributed over the city rather than being absorbed [12].

In this paper, an efficient engineering model is proposed, based on fitting to an extensive set of FDTD (finite difference time domain) simulations [13, 14] of canyon-to-canyon sound propagation. This model uses an analytical function of a complexity comparable to ISO 9613 formula for noise barriers and aims to calculate the background noise in the shielded areas of a city, which could then be added to the noise maps which commonly underestimate levels at highly shielded locations.

2. Reference simulations and setup

As a basis for deriving the engineering formulation, several configurations of canyons have been simulated using the FDTD method. The configurations cover different source canyon width, receiver canyon width and the intermediate building width, as well as different building height on both sides of the canyons. The canyon widths vary from 4.8 meters to 38.2 meters and the height of the buildings range from 0 to 16 meters, including the typical building height in traditional European cities.

The building properties are modeled as realistically as possible by assigning different materials and making the surfaces rough. The façade surface are assigned the impedance of glass and bricks alternately along the height. Receivers are located along the façade and across the canyon. A typical simulation configuration is shown in figure 1(a). Since the sound waves will travel a long distance because of multiple reflections, air absorption is included by a wavelet approach [15, 16], under the condition that temperature is 10 °C and relative humidity is 70%.

3. Effect of multiple reflections

3.1. Contribution of canyons

Compared to free field, the sound pressure level at the top of the canyon will be higher due to reflections, which depends on the canyon width, the height of the intermediate building and the canyon buildings, as well as the façade materials. If the building height of the source canyon or the receiver canyon is set to zero, the effect of a single canyon can be obtained by changing the building height of the opposite canyon. In figure 2, H_r=0, H_i=10 m, W_s=W_r=9.6 m, W_i=10 m and H_s has been varied. For the same geometrical configuration, the canyon effect is largely independent of frequency, see figure 2.

The simulation results show that the sound level in the receiver canyon rises with increasing heights of the canyon, approaching to an upper limit when $H_s > 2 * H_i$. This threshold value considerably relates to the height of the intermediate building. Figure 4 shows an example of 500Hz. The slope grows slower both for H_i=9.6 m and H_i=6.4 m and it levels off at smaller H_s value when H_i is lower.

Based on this setting: H_s=0, W_s=W_r=9.6 m, W_i=10 m and only does H_r changes, similar trends of receiver canyon can be observed, although the geometry of the source canyon is more important when looking at shielding (figure 3). For example, the effect saturates to a threshold (figure 4) and the effects are independent of wave lengths. The weaker effect can be explained by the higher receiver height which is a little higher than the source height.

3.2. Engineering approximation

The proposed engineering approach extends the ISO 9613 term for attenuation by noise barriers. ISO9613 proposes how to calculate the sound propagation over barriers. Rather than to explicitly calculate these multiple reflections, we propose to add an additional term to the ISO9613 formula for screening by noise barriers. The additional

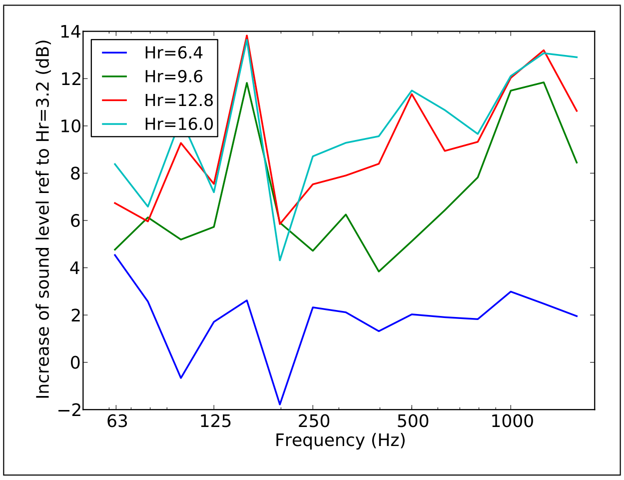

Figure 3. Receiver canyon effect respect to frequencies.

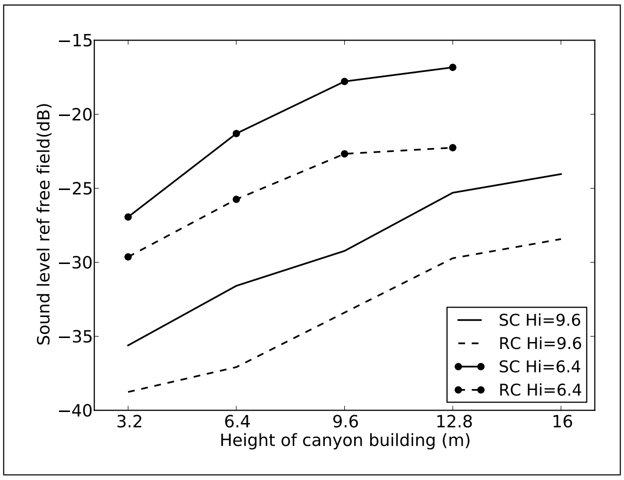

Figure 4. Canyon effect(500Hz) as the function of the height of the reflecting building, where “SC” is the source canyon; “RC” is the receiver canyon.

terms are chosen in such a way that in the limiting case where H_s or H_r tend to zero or W_s or W_r tend to infinity, the additional terms vanish. Considering the previous analysis, equation 1 is fitted to over 200 FDTD simulations.

$$
\begin{aligned}
Atte = \\
& \underbrace{A \cdot ISO}_{ISO} - \underbrace{B \cdot \frac{N_3}{\alpha \cdot N_1 + N_3}}_{H_s} \\
& - \underbrace{C \cdot \frac{N_4}{\alpha N_2 + N_4}}_{H_r} - \underbrace{D \cdot \frac{dN_2 \cdot H_r}{H_r + W_r}}_{extra\ H_r} \qquad (1)
\end{aligned}
$$

Where, “Atte” is the total attenuation; $N1 = \frac{d11-d12}{\lambda}$, $N2 = \frac{d21-d22}{\lambda}$, $N3 = \frac{d31-d32}{\lambda}$, $N4 = \frac{d41-d42}{\lambda}$ (d11, d12 and other symbols definition can be found in figure 1(b)); A, B, C and D are fitting coefficients and α is used to limit H_s and H_r part to reasonable values when N_3 or N_4 approaches to infinity; dN_2 equals to $\frac{N_2}{\lambda}$. Based on

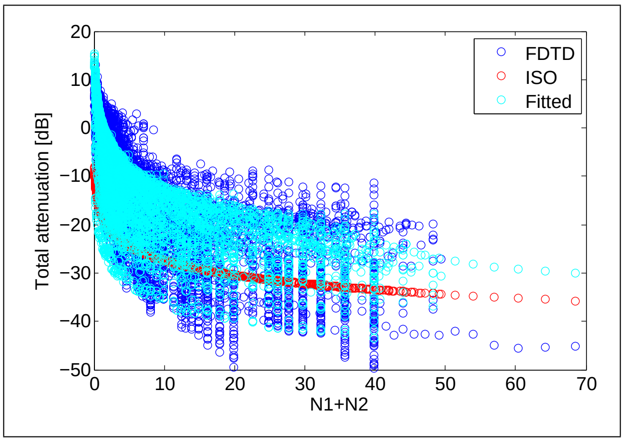

Figure 5. Fitting results as a function of the partial Fresnel numbers.

the current simulation data set, the coefficients $A = 1.4$, $B = 21.5$, $C = 11.2$, $D = 2.6$ and $\alpha = 0.3$ can fit a good results, shown in figure 5.

4. Comparing with measurement

An inner city noise measurement network in Gent (Belgium) with nodes placed at shielded locations is used to validate the current methodology. When running the calculation, the source spectrum of Harmonoise was used. The traffic intensity is provided by the database of the Flemish government. A typical city region of Gent is modeled and two of the measurement positions are chosen as examples of comparison, shown in figure 6. The building coordinates are extracted from GIS system, while the heights of the building here are assumed to 8 meters. The measurement data of 5 weekdays from 10am to 17pm are used to avoid outlying traffic situations. The comparison results are shown in figure 7 and figure 8. In this calculation only the main roads are considered as the sources. The calculation region is up to 1km from every receiver. Although the total L_{Aeq} is acceptable, the low frequencies are overestimated and the high frequencies are underestimated which may be caused by the neglecting the influence of the intermediate canyons. Another reason could be that the traffic intensity data of the major road could include more low frequency elements than than the inner-city roads and in this calculation only are the major roads considered. For the high frequencies, the measurement can be affected by non-traffic related sounds, but also the neglection of turbulent scattering can play a role here.

5. Conclusions

In this paper, an efficient engineering model to calculate the background noise level is proposed. This model combines part of the ISO term and an extra correction for multiple reflections, aiming to predict the background noise in a large region. The comparison between measurement and calculation shows that although the total estimating

Figure 6. Map of the comparison position. The red icons are the two comparison positions.

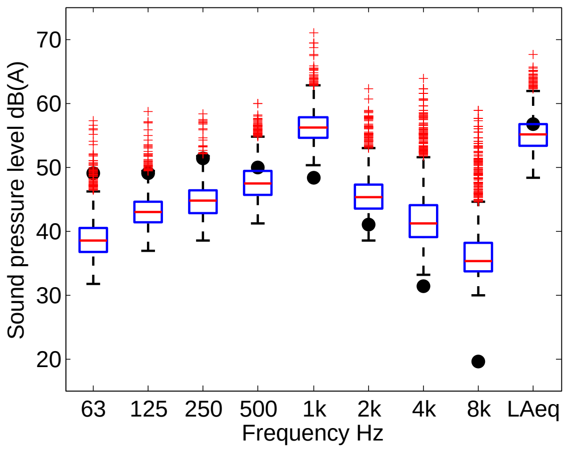

Figure 7. Comparison between calculation and measurement, position 1.

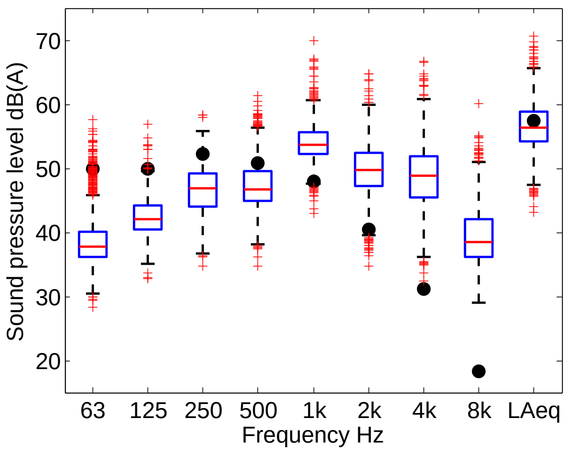

Figure 8. Comparison between calculation and measurement, position 2

value is acceptable, the low frequencies are overestimated. The future work will focus on including the intermediate canyons and the turbulent scattering. The latter might explain the deviation of the factor A in Equation 1 from unity. The range of applicability of the proposed formula will further be extended by including more simulated cases and measurement locations.

Acknowledgement

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