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Improving the accuracy of engineering models at shielded building facades: experimental analysis of turbulence scattering

Timothy Van Renterghem[1], Weigang Wei[2], Jens Forssén[3], Maarten Hornikx[4], Mikael Ögren[5], Dick Botteldooren[6], Erik Salomons[7]

[1,2,6] Ghent University, Department of Information Technology, Sint-Pietersnieuwstraat 41, B-9000 Gent, Belgium

[3,4] Applied Acoustics, Chalmers University of Technology, Gothenburg, Sweden

[4] Building Physics and Services, Eindhoven University of Technology, P.O. box 513, 5600 MB Eindhoven, The Netherlands

[5] Department of Environmental and Traffic Analysis, VTI, Gothenburg, Sweden

[7] TNO Urban Environment and Health, Delft, The Netherlands

ABSTRACT

Noise mapping models are able to accurately predict directly exposed facade levels near busy roads on condition that sufficiently detailed traffic data is available. At the non-directly exposed side of the building, however, common practice application of standard methods strongly underpredicts sound pressure levels, potentially leading to an incorrect assessment of noise annoyance and sleep disturbance. The concept of background noise mapping was proposed before, which has the important advantage that it can increase the accuracy of existing noise maps at a limited computational cost. In this study, long-term meteorological and noise data showed that turbulence scattering contributes significantly to the noise level at shielded facades, already at sound frequencies below 1 kHz. Periods with strong atmospheric turbulence are dominant for long-term equivalent noise levels as typically used in strategic noise maps. A comparison between predictions and measurements show that rather high turbulence strengths should be used when producing noise maps.

Keywords: urban sound propagation, quiet sides, atmospheric turbulence

1. INTRODUCTION

Preserving or promoting a quiet side near a dwelling helps to reduce noise annoyance and sleep disturbance in the urban environment. This was shown by small-scale and large-scale surveys in different countries [1][2][3]. The presence of the bedroom at the quiet facade was shown to be an

[1] timothy.van.renterghem@intec.ugent.be
[2] weigang.wei@intec.ugent.be
[3] jens.forssen@chalmers.se
[4] m.c.j.hornikx@tue.nl
[5] mikael.ogren@vti.se
[6] dick.botteldooren@intec.ugent.be
[7] erik.salomons@tno.nl

important aspect, not only to reduce noise-induced sleep disturbance, but also to limit the self-reported noise annoyance at home in general [3].

While street-side predictions are typically reasonably accurate on condition that detailed traffic data is available, level estimates at shielded locations are usually problematic as shown with long-term measurements in Ref. [4]. The main reason is the need to fully consider the complex physics of sound propagation in street canyons like the multiple specular and diffuse reflections, in combination with diffraction over (complexly shaped) roofs. Although accurate calculation methodologies are available for such sound propagation problems, these cannot be directly used to produce noise maps due to the large computational cost. The concept of background noise mapping has been introduced in Ref. [4] to overcome this problem, allowing to correct levels at shielded facades “a posteriori”.

In addition, turbulence scattering of sound in the urban atmospheric boundary layer influences noise shielding to an important degree [5] and further complicates predictions. It was shown in Ref. [4] that by just relying on multiple reflections and diffractions, accurate predictions above roughly 1 kHz are not possible.

The main purpose of this paper is assessing the variability in the sound level measured at highly shielded locations in a dense urban setting, and to what degree this can be linked to meteorological data. The effect of atmospheric turbulence on long-term equivalent levels as commonly used in noise maps is studied as well.

2. DATA

2.1 Meteorological data

Wind speed, wind direction, relative humidity, rainfall intensity, air temperature, and atmospheric pressure were available as hourly averages from an inner city meteorological observation point above roof level. Direct solar irradiation (in W/m^2) was available from a location near the city border.

2.2 Noise data

IDEA-noise nodes [6] measured 1-s equivalent sound pressure levels in 1/3-octave bands. The concept behind the IDEA-project is using (cheap) consumer-electronics microphones for environmental noise monitoring. It was shown by long-term outdoor testing that differences relative to type 1 reference equipment stay below 1-2 dBA for road traffic noise monitoring [6].

Focus in this paper is on a single location (see Figure 1) with simultaneous measurements at both the directly exposed and shielded building side. As the noise levels were gathered as part of a research project aiming at developing and testing the noise nodes and network aspects, there are missing periods.

Figure 1 – Areal photograph indicating the front (*red* dot) and back (*green* dot) facade noise nodes and surroundings.

3. TURBULENCE STRENGTH PREDICTION

The Harmonoise meteorological classification framework [7] has been used to estimate values of turbulence related parameters u* (friction velocity), T* (temperature scale) and 1/L (inverse Monin-Obukhov length). Estimates of these are provided [7] based on common meteorological observations like wind speed, cloudiness, and time of the day. Cloudiness during daytime (in octas) was estimated based on solar insolation. The temperature and velocity structure constants (C_T^2 and C_v^2) are estimated following Ref. [8], although these formulas were not specifically designed to take into account the influence of the urban structure on atmospheric turbulence. The largest values predicted are C_v^2=1.00 $m^{4/3}/s^2$ and C_T^2=0.03 $K^2/m^{2/3}$.

4. NOISE LEVEL VARIABILITY

In Figures 2 and 3, the measured hourly equivalent noise level distribution (during daytime, between 7 h and 19 h) is shown at the directly exposed and shielded facade. The data is split up in "weak" ($C_v^2+C_T^2<0.1$) and "strong" ($C_v^2+C_T^2>0.3$) turbulence by using the Harmonoise turbulence prediction framework as described in Section 3. Hours with rainfall were not retained in the dataset.

At the most exposed facade, a very similar distribution is observed under both atmospheric conditions. A small offset is observed between the two categories. No normalization has been performed for the variation in traffic intensity during the day, although the occurrence of weak and strong turbulence will typically depend on the time of the day. Similar distributions are found over the full frequency range.

At the shielded side, strong turbulence gives rise to a large variation in hourly equivalent sound pressure levels, and this variation increases with frequency. The difference in sound pressure level between the first and third quartile can be as large as 15 dB at 4 kHz under strong turbulence. At very low frequencies a similar distribution is found as at the front facade. The median of the noise levels under weak turbulence are clearly lower than at high turbulence, already at rather low sound frequencies.

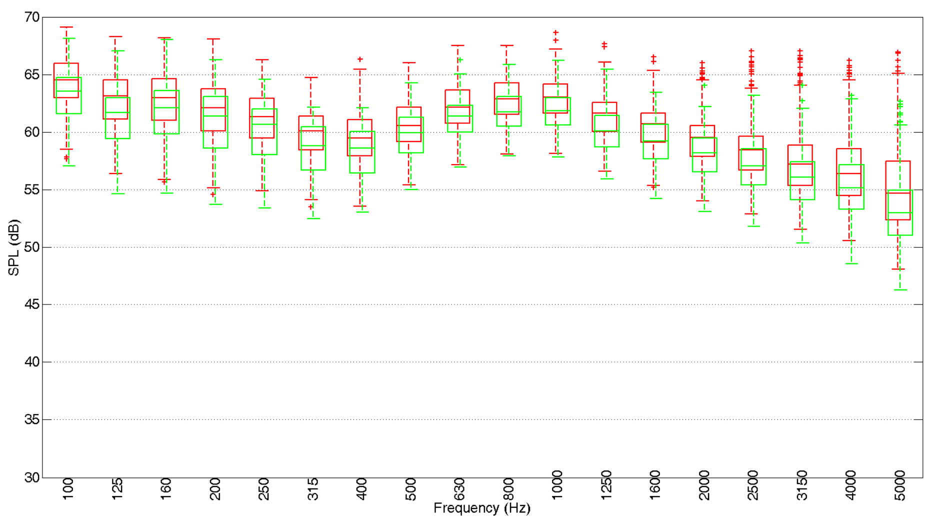

Figure 2 – Boxplots showing the (measured) level variation over time in 1/3-octave bands (hourly averaged, non-weighted, equivalent sound pressure levels) at the directly exposed facade. The distinction is made between weak turbulence (*green*) and strong turbulence (*red*). The (middle) horizontal line in the box indicates the median of the data. The box is closed by the first and third quartile. The whiskers extend to 1.5 times the interquartile distance above the maximum value inside the box, and to 1.5 times the interquartile distance below the minimum value inside the box. Data points that fall outside these limits are indicated with the plus-signs.

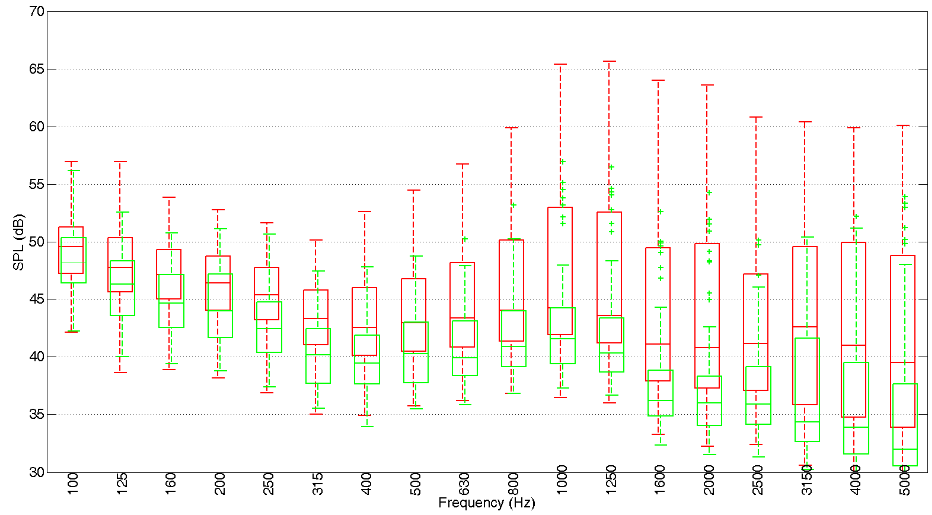

Figure 3 – See caption of Figure 2, but now for the shielded facade.

5. LONG-TERM NOISE LEVEL PREDICTION

Measured L_{day}, over the full period considered at hours where both noise and meteorological data were available, are depicted in Figure 4, averaged separately over weak and strong turbulence moments. Predictions with the background noise mapping model [4], applied to the location under study, are shown as well. The traffic data from the approved noise maps for the agglomeration of Ghent (following the Environmental Noise Directive 2002/49/EC) was used. Calculations are provided taking into account diffraction and multiple reflections between building facades [4], and a turbulence scattering engineering model [9] using the turbulence structure values close to the largest ones as estimated before in both the weak and strong turbulence class (see Section 3).

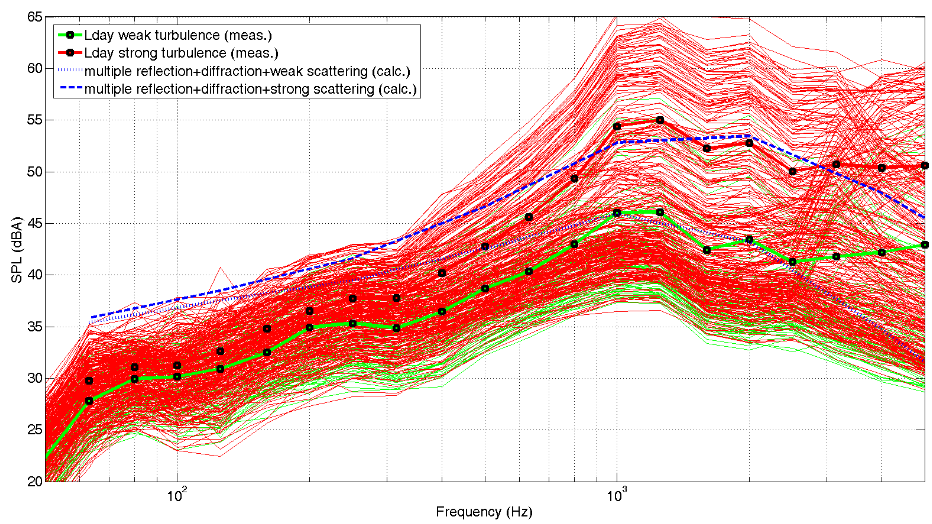

Figure 4 – Measured and calculated spectra at the shielded location. All hourly equivalent sound pressure level spectra are shown as well (thin green and red lines) that form the basis for the energetically averaged values L_{day}.

The measurements show that at low sound frequencies the difference between weak and strong turbulence is limited. Above 1 kHz, this difference can be near 10 dB for long-term equivalent noise levels. Turbulence scattering is therefore essential for accurate predictions at shielded locations in a city. The background noise mapping model shows good agreement near the maxima in the spectra. There is a tendency to overpredict the low frequency content at the current location.

Other sounds like e.g. the rustling of leaves might be present in the measurements at the shielded side, especially during moments of strong turbulence, often characterized by high wind speeds. In addition, there is a railway track parallel to the road at the front facade (see Figure 1) while the calculations only take into account road traffic noise sources.

Refraction by wind from the dominant road at the front facade is not expected due to the small distance relative to the microphone. However, long-distance refraction from other roads and highways could not be excluded, although specific wind directions could not be linked to increased or decreased sound levels at the current site.

6. CONCLUSIONS

Including turbulence scattering when predicting sound levels at shielded locations in a city showed to be essential. Atmospheric turbulence leads to a strong variation in (hourly) equivalent sound pressure levels, yielding both low and high values. Periods with strong turbulence scattering become dominant for long-term equivalent noise levels. In noise mapping efforts, reasonably high values for the turbulence strength are therefore needed.

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