inter.noise 2010
noise and sustainability
13-16 June 2010 . Lisbon . Portugal
www.internoise2010.org

AN EXPERIMENTAL STUDY OF THE USE OF ACOUSTIC DIFFUSERS TO REDUCE NOISE IN URBAN AREAS

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Abstract
The use of acoustic diffusers to reduce noise in urban areas has been recently numerically investigated [Acta Acustica united with Acustica, Vol. 95 (2009), p. 653–668]. It was shown that a significant noise reduction can be observed by considering diffusers on the building façades. In the present study, an experimental investigation is proposed to validate last results. Measurements are carried out using a 1:10 urban street scale model, with and without acoustics diffusers, in order to evaluate the “real” effect of such devices, for several configurations. Results, in terms of sound attenuation and reverberation, show that a positive effect can be observed, provided that diffusers are well designed for the reduction of road traffic noise.

Keywords: Urban acoustics, noise reduction, acoustic diffusers

1 Introduction

Urban acoustics has attracted many studies over the last decades, mainly in the aim to reduce noise in urban areas. Among the noise reduction strategies, the reduction at the source of the transportation noise is widely considered. Another strategy consists in correcting the acoustic properties of urban spaces to reduce the noise propagation. Like in room acoustics, several solutions can be considered, based on absorption and diffusion devices, to reduce noise level and the reverberation within the street.
However, there are however very few studies about the acoustic treatment of urban spaces. Kang, as well as Horoshenkov *et al*, have suggested to consider absorbent patches on the façades and on the ground to reduce the noise propagation in streets [1] [2]. Hornikx and Forssén have investigated the use of oriented patches (absorption and diffusion) as a façade

treatment to reduce noise in shielded canyons [3]. In a recent paper, the use of acoustic diffusers to reduce noise in urban areas has been recently numerically investigated [4]. It was shown that a significant noise reduction can be obtained by considering diffusers on the building façades, producing uniform diffusion over the frequency bands of interest (i.e. the traffic noise spectrum). Moreover, a significant effect is observed if the relative surface of diffusers is larger than 20%, the diffusers are located on the lower part of the building façades (i.e. at the source height), and additionally, if absorption is added on diffusers.
As a possible solution, the use of acoustic diffusers based on quadratic residue sequences [5], optimized on the traffic noise spectrum, was recently proposed [6]. In the present study, an experimental investigation is proposed to validate the effect of such urban acoustics diffusers. Measurements have been carried out using 1:10 urban street scale models, with and without acoustics diffusers on the building façades, in order to evaluate the “real” effect of such devices on the sound attenuation and on the reverberation within the street.
This paper begins with a description of the experiment (section 2), following by preliminary results (section 3). Lastly, we conclude on the effect of acoustic diffusers on the noise reduction in urban areas (section 4).

2 Experiments

2.1 Acoustic diffusers

Since it was shown that diffusers creating uniform diffusion seem to produce a significant noise reduction [4], the choice was done to consider 2D Schroeder’s diffusers based on quadratic residue sequence (QRD) [5], designed to produce optimum diffusion for the frequency of the usual road traffic spectrum (i.e. [100-5000] Hz, with a maximum energy around the third-octave band 1000 Hz) [6]. One of the proposed diffusers is based on a QRD of length N=7, defined by wells with a maximum depth of 18 cm and a size of 10 cm, leading to a design frequency of 810 Hz and a upper frequency of 1700 Hz. It must be noted that these frequencies are just “theoretical” limits and not limits for the diffusion quality. Indeed, it was observed that diffusion still occurs above the upper limit, and below the lower frequency [5]. In order to make the diffuser symmetric, a 8th row and 8th column are added, which gives a diffuser of size 80 cm x 80 cm. A second diffuser without thin fins was also considered, since it is easier and cheaper to built such diffusers (left of Figure 1).
In order to characterize these diffusers, an experimental investigation has been carried out [6], which shows that the maximum diffusion coefficient is around 0.5 on the frequency range [500-1400] Hz for the first diffuser. On the other hand, the diffuser without thin fins has complementary performances with a maximum diffusion coefficient around 0.4 below 500 Hz and above 1400 Hz. For both cases, the upper limit of diffusion is around 2000 Hz, i.e. about the predicted upper frequency. In conclusion, the diffuser with thin fines produces an expected diffusion pattern between 500 Hz and 1400 Hz and seems well adapted to reduce road traffic noise. For noise outside this frequency range (i.e. mainly for lower frequencies), the diffuser without thin fins could give interesting results.

2.2 Street scale model

A 1:10 street scale model of 0.70 m high (i.e. 7 m full scale, 7 mFS), 4 m length (40 mFS) and variable width was carried out (Figure 2). The building façades were simulated by 1 cm thick plywood with varnished surfaces, which is acoustically hard enough to simulate concrete blocks. The street pavement is made by a painted concrete floor. All the surfaces in

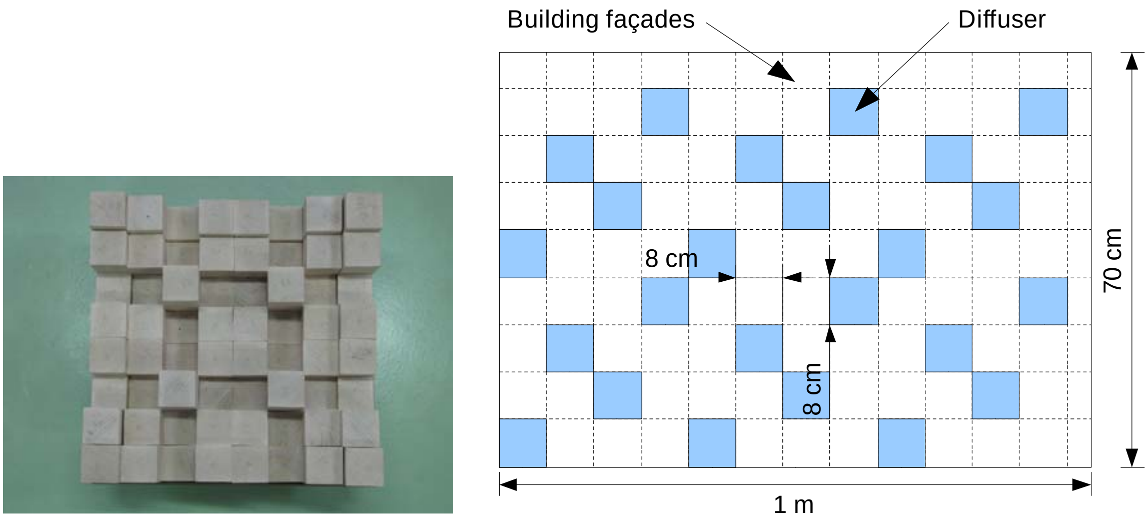

Figure 1 – Left: Diffuser geometry: QRD without thin fins. Right: arrangement of diffusers along 1 m (10 mFS) of a building façade. The 8x12 pattern (height x length) is repeated along the façade surfaces. The area covered by diffusers is about 22% of the whole surface area.

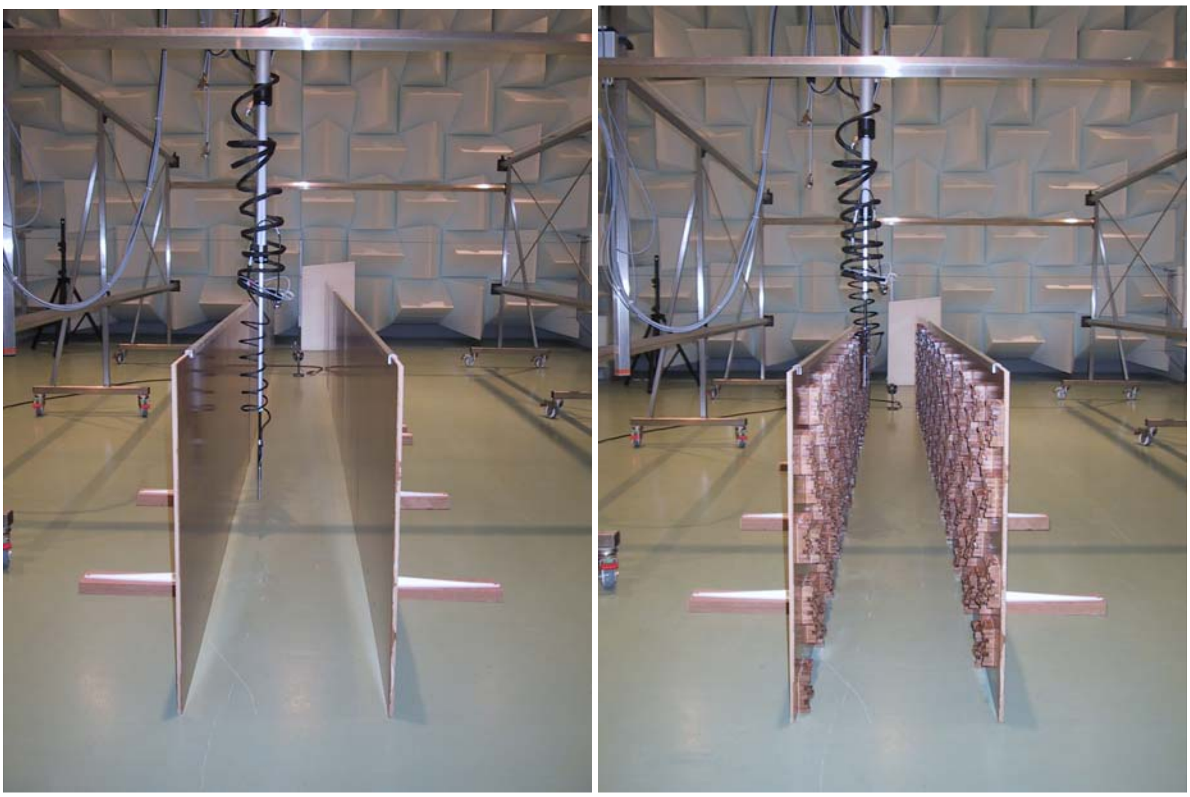

Figure 2 – Scale model of a street of 4 mFS width (configuration 1).
Left: reference configuration (without diffuser). Right: configuration with diffusers. Similar street scale models have also been considered with a street width of 7 mFS (configuration 2) and 10 mFS (configuration).

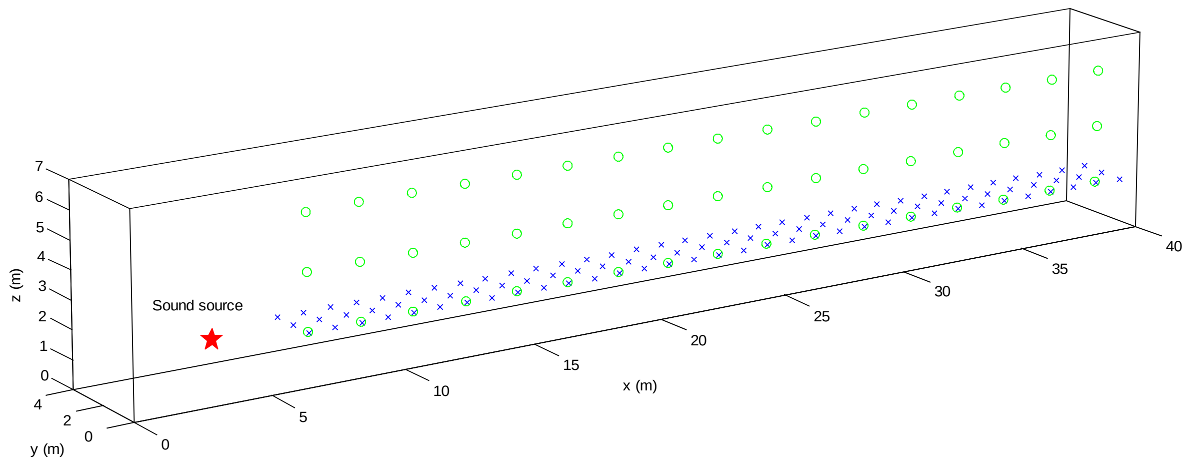

Figure 3 – Positions of the sound source and receivers in the street (example of Conf. 1, with a street width of 4 mFS). Green circle: vertical grid with 17 x 3 = 51 receivers (regular step of 2 mFS; same grid for Conf. 2 and Conf. 3) at 1 mFS from the left façade; blue cross: horizontal grid (regular step of 1 mFS) at 1.5 mFS high with 34 x 3 = 102 receivers (Conf. 2: 34 x 6 = 204 receivers; Conf. 3: 34 x 9 = 306 receivers).

the scale model can be initially defined as quasi-specular surfaces, with low acoustic absorption. All measurements were carried out inside a semi-anechoic room.
A pseudo-random arrangement of diffusers on both façades (right of Figure 1), has been considered for three street widths 4 mFS (Conf. 1), 7 mFS (Conf. 2) and 10 mFS (Conf. 3). The surface area covered by diffusers is about 22% of the whole façade area. For each case, a reference configuration was also considered, corresponding to the same street without diffuser. For practical reasons (since it is easier to built such diffusers in a scale model), only the diffuser without thin fins was considered.

2.3 Measurements

An omni-directional source was located in the middle axis of the street (y_S=2 mFS, 3.5 mFS and 5 mFS), at x_S=4 mFS from the first extremity and z_S=1.5 mFS high. Measurements were realized along a horizontal grid (at the source height) with a regular spatial step of 1 mFS and a vertical grid (at 1 mFS from a façade) with a regular spatial step of 2 mFS (Figure 3), using a ¼-inch microphone Bruël & Kjær Type 4939, connected to a Pulse Analyser Platform. The microphone was set up on a 3D robot, in order to have an automatic displacement, coupled with the acoustic measurement system. For each location of receiver, impulse responses were recorded using a white noise reference signal. Since, only the effect of diffusers is studied in this paper (i.e. a comparison of the acoustical parameters between the reference configuration and the same case with diffusers), the excess of atmospheric absorption in the street scale model (in comparison with the full scale model) was not compensated.
The post-processing of each impulse response allows then to calculate sound pressure levels (SPL) and reverberation times (RT and EDT) for each third-octave band between 100 Hz FS and 5000 Hz FS. In order to simplify the presentation of the results, only the measurements along the horizontal grid are presented here. Moreover, since it was shown that the sound field is almost uniform along a transverse line of the street (perpendicular to the façades, for a given height), acoustical parameters (SPL, RT and EDT) were averaged

along transverse grid lines, leading to a single value at a given distance from the sound source.
Finally, several parameters have been studied to evaluate the effect of diffusers on the propagation in a street. Firstly, the absolute sound pressure level in the street has been considered. To characterize the effect of diffusers for a street configuration, by comparison with the same street without diffuser (i.e. with perfectly specular reflecting façades), a mean sound level difference (in dB) is calculated as the mean difference of sound pressure level between both configurations. Secondly, to qualify the sound attenuation for each configuration of diffusers (i.e. the sound pressure level as a function of the distance along the street length), an attenuation coefficient m in dB per metre was also introduced. To avoid the effect of the direct field, which is preponderant close to the sound source and that is almost the same for all configurations, the attenuation coefficient has been obtained through a linear interpolation of the sound levels beginning at 5 mFS from the sound source until the opposite street extremity. Lastly, to compare a street configuration (conf) with the reference street (ref), the relative deviation (in percent) of the sound attenuation was calculated as:

$$\sigma_m = \frac{m_{\mathrm{ref}} - m_{\mathrm{conf}}}{m_{\mathrm{ref}}} \times 100\% \,. \qquad (1)$$

When the relative deviation is negative, it corresponds to an increase of the sound attenuation, which is a wanted effect. Finally, the relative deviation (in percent) of the sound decay has also been calculated, similarly to equation (1), replacing m by RT or EDT. When the corresponding relative deviation is positive, it corresponds to a decrease of reverberation time, which is a wanted effect again.

3 Results

Figure 4 shows the mean SPL and the mean reverberation times RT and EDT, with the corresponding standard deviation, in function of the position along the street (the sound source is located at 4 mFS) for the 1/3 octave bands 400 Hz FS and 4000 Hz FS, for the configuration 1, with and without diffusers. One can firstly remark that the standard deviation is larger for the lower frequency, due to interference effects at low frequencies, producing non-uniform sound field in a street section. This is particularly visible for the case without diffuser (reference configuration with specular reflection), on the sound level and on the reverberation times. One can also note an inflection point in the sound attenuation curve for the reference configuration, for the third-octave band 400 Hz FS, at position 13 mFS. This inflection point is also visible at other lower frequencies, as well as for the configuration 2 with a larger width. This particular position corresponds to the reverberation distance [7], which has been found at the same order of magnitude in other streets [8].
When comparing the mean SPL between the reference configuration and the configuration with diffusers, one can note a positive effect of diffusers for the third-octave band 400 Hz FS, from 15 mFS to the end extremity, with a noise reduction reaching 5 dB to 10 dB. A decrease of the reverberation (EDT and RT) is also observed along the street length. The effect is stronger on the RT because the diffusers reduce the occurrence of flutter echoes (in the late part of the decay). These flutter echoes are the results of sound energy trapped between the two façades (Figure 5). The diffuser effect is lower for the 1/3 octave band 4000 Hz FS both for the mean SPL and the mean reverberation, and is mainly visible from the middle of the street only.

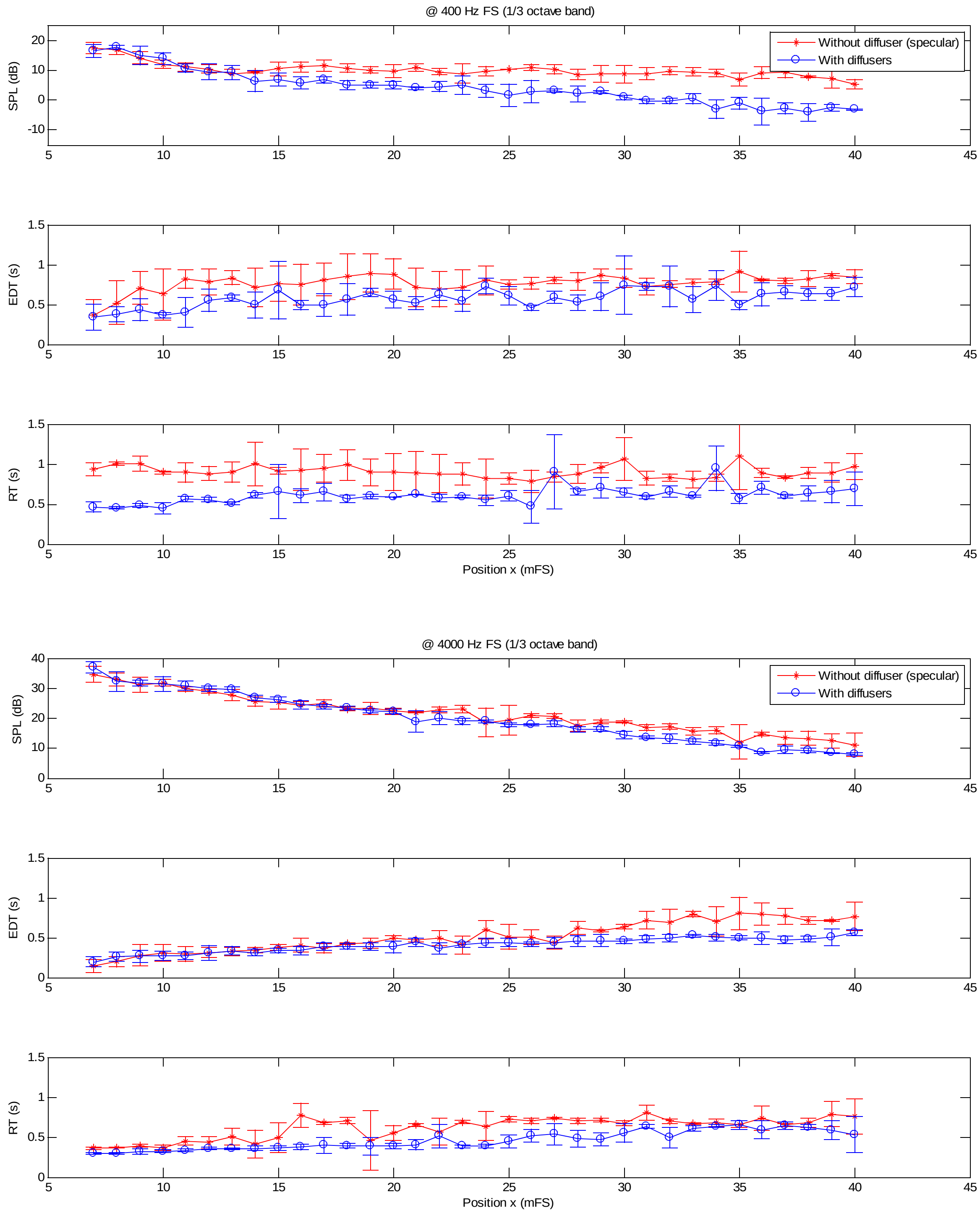

Figure 4 – Experimental results (SPL, EDT, RT) for the street configuration 1 (street width of 4 mFS) for the 1/3 octave band 400 Hz FS and 4000 Hz FS, according to the position in the street. *Y*-scales are equivalent between third-octave band, for each parameter (SPL, RT, EDT).

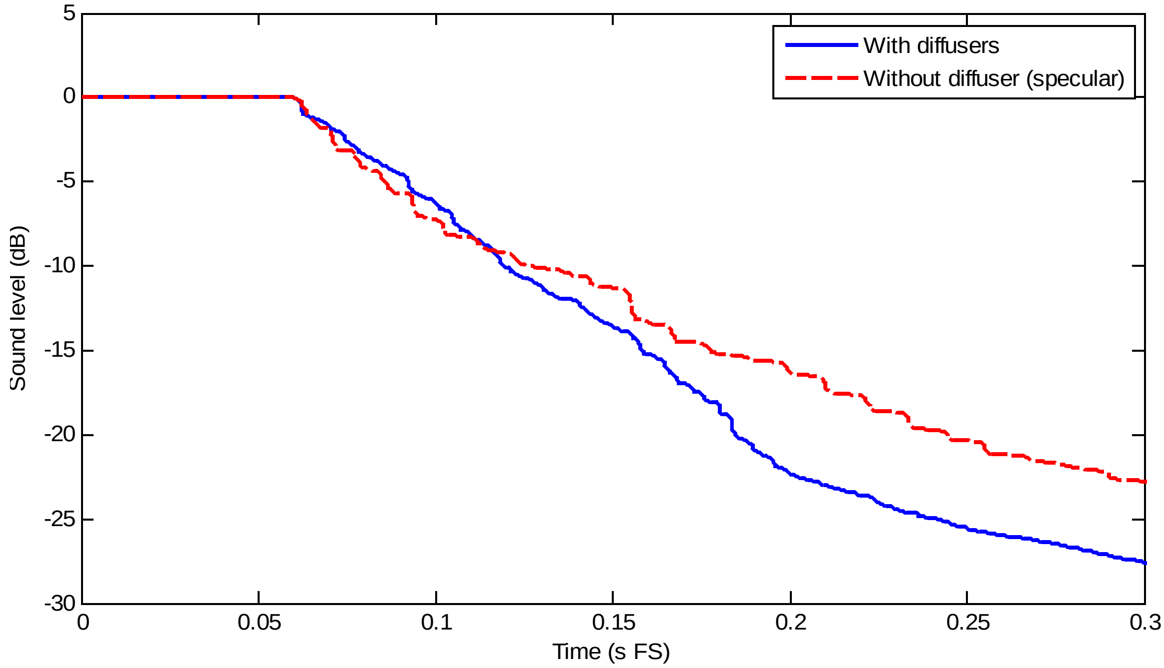

Figure 5 – Normalized sound decay at 21 mFS from the source, at the source height, in the middle axis of the street (configuration 1), with and without diffusers (third-octave band 400 Hz FS).

The diffuser effect for the street configuration 1 is summarized on Figure 6 presenting the mean sound attenuation (in dB/m) and the mean reverberation times for each third-octave band between 100 Hz FS and 5000 Hz FS. Concerning the sound attenuation, the diffuser effect is visible for all third-octave bands from 200 Hz FS. The relative deviation from the reference configuration 1 (see Figure 7 for configuration 1) is on the order of few percents to nearly -300%. In the last case, it means that the sound attenuation is 4 times higher with diffusers than without (see equation (1)). The same observation can be done for larger street widths (configurations 2 and 3), with a maximum of the diffuser effect occurring for the third-octave bands 315-500 Hz FS and 1600-2000 Hz FS. These frequencies corresponds to the ones for which the diffusers are the most efficient, i.e. the diffusion coefficient is the largest (see section 2.1 and reference [6]). Concerning the reverberation times, Figure 7 shows that diffusers produce a decrease of reverberation around 30-50% whatever the frequency and the street width.

4 Conclusions

The use of acoustic diffusers to reduce noise in urban areas has been numerically investigated in the past, showing that a significant noise reduction can be observed both in terms of sound level and reverberation. In the present study, an experimental investigation is proposed to validate the effect of acoustic diffusers in streets, using 1:10 urban street scale models, with and without diffusers on the building façades.

Experimental results show that the diffusers a positive effect is observed on the spatial sound attenuation in the street with diffusers, for the frequency ranges for which the diffusion coefficient of the diffuser is the largest. For the narrow street (configuration 1), the sound level difference is, for instance, around 10 dB at the street extremity, at the third-octave band 400 Hz FS. However, this effect on the sound attenuation decreases when increasing the

street width. Whatever the street width and the frequency, the diffusers produce a decrease of the reverberation in the street, with a mean reduction around 35% for the RT and 30% for the EDT.
To conclude, the use of diffusers on building façades could enable a reduction of noise level in urban areas, provided that the diffuser is designed to have the largest diffusion coefficient at the frequency range of the noise of interest. Moreover, a significant decrease of reverberation is observed, whatever the frequency. In addition, the whole effect of diffusers could probably be increased by increasing the diffusers area on the façades as well as by adding absorption on diffusers.
It must be noted that the effect of diffusers was estimated by comparing the results with specular façades. However, in real urban areas, façades already incorporate many irregularities, creating a large amount of diffuse reflections naturally [9]. The effect of diffusers in a real street is then probably lower than the one observed in the present investigation. Lastly, in real streets, multiple noise sources are present simultaneously at several locations along the street. The far field effect that is observed for the sound level attenuation in a street with acoustic diffusers for a single sound source, becomes unimportant in terms of absolute sound pressure level. Consequently, this strategy would be more adapted at the boundaries of quiet areas like mall.

Acknowledgments

The authors wish to thank the Agence de l’Environnement et de la Maîtrise de l’Énergie (ADEME) for providing financial support of the experimental part of this work.

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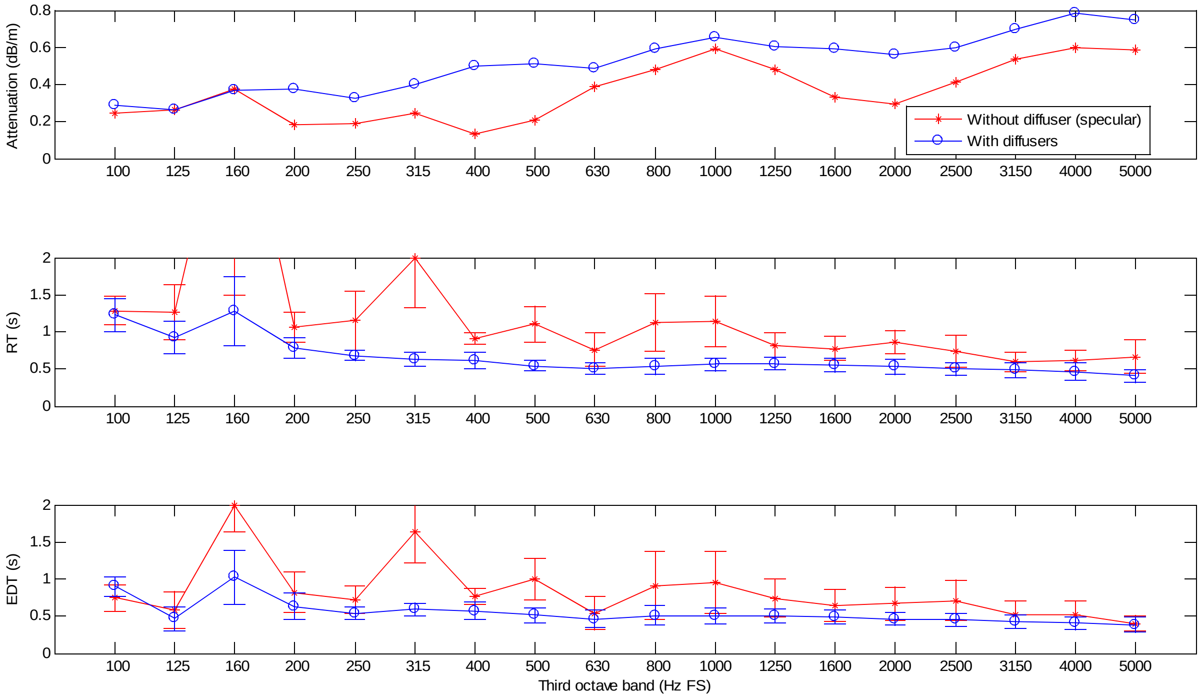

Figure 6 – Summary of experimental results (mean attenuation, RT and EDT) for the street configuration 1 and the reference, for all third-octave bands between 100 and 5000 Hz FS.

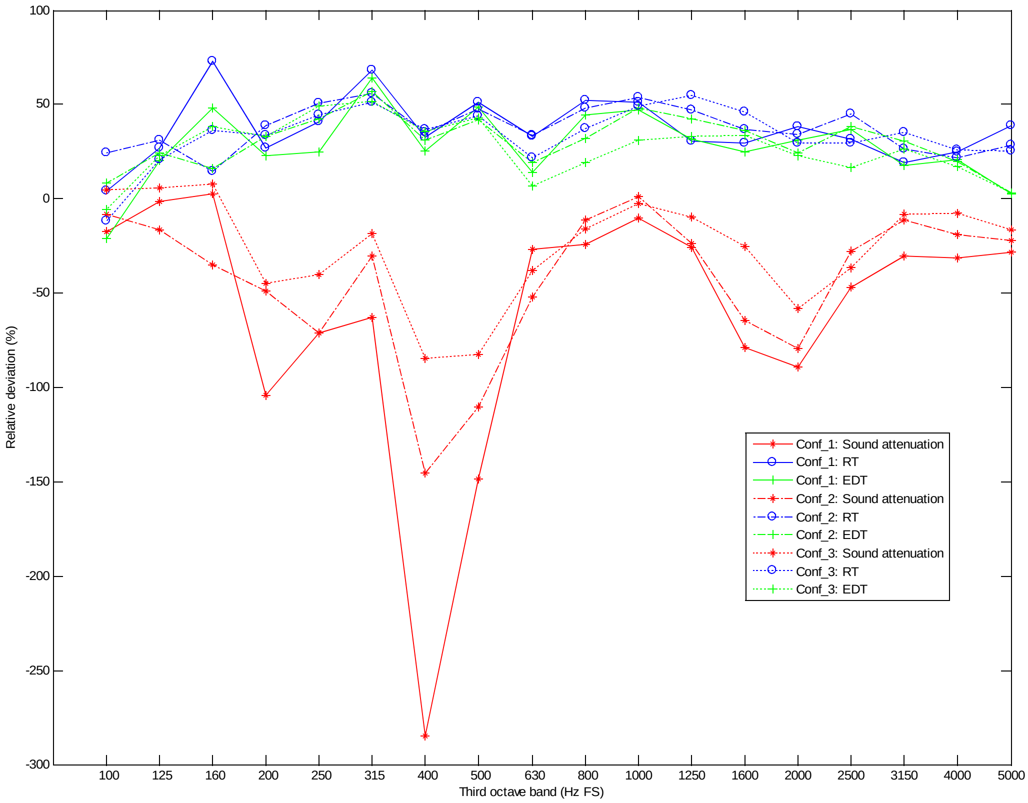

Figure 7 – Relative deviation (in %) of sound attenuation, RT and EDT for the street configurations 1 (Conf_1), 2 (Conf_2) and 3 (Conf_3), for all third-octave bands between 100 and 5000 Hz FS.