Effects of the window mounting conditions on the auditory perception of transmitted environmental noises

Arnaud Trollé, Catherine Marquis-Favre and Julien Faure
Laboratoire des Sciences de l’Habitat, DGCB URA CNRS 1652, Ecole Nationale des Travaux Publics de l’Etat, Rue Maurice Audin, F-69518 Vaulx-en-Velin Cedex, France, e-mail: {trolle,marquis}@entpe.fr.

A window represents a weak point of the building shell towards outdoor noises, in spite of the improvement of its acoustic performance. Therefore, recent sound quality studies have emphasized the significant role of auditory evaluation in the assessment of the acoustic performance of a structure. Thus, coupling between physical analysis and auditory evaluation of noises transmitted through a window has allowed recommendations to be provided for structural modifications more suited to improve acoustic comfort. These recommendations notably concern mounting conditions of the thin glass plate in its window frame. In previous studies, window was modelled as a thin glass plate with viscoelastic boundary conditions and excited by a pink noise. The present study still considers such a modelled plate but excited by environmental noises. The window acts as a filter towards the transmitted environmental noises. This paper deals with the effect of the window mounting conditions on the auditory perception of these transmitted noises. Filtered sounds are obtained by convoluting a binaurally recorded environmental noise (aircraft noise, road traffic noise, etc.) to the impulse response of different filters corresponding to different mounting conditions of the window. Then, the obtained stimuli are submitted by pairs to a jury of subjects who are asked to give dissimilarity and preference judgments. For each environmental noise source, all the filters are qualitatively evaluated. Analysis reveals that, among filters which are equivalent in acoustic performance (i.e. same $R_w$), some mounting conditions may be more adapted from a perceptual point of view to a given outdoor sound situation. The different obtained trends will be discussed.

1 Introduction

Recent research [1, 2, 3] have shown that auditory evaluation of sounds radiated from plates could lead to a better sound quality of these components of many structures. For building applications, Faure et al. [4] have studied the effects of the glazing viscoelastic boundary conditions on the auditory perception when a pink noise type excitation is considered; by coupling physical analysis and auditory evaluation, they have provided recommendations for glazing mounting conditions in its window frame likely to improve acoustic comfort in dwellings. The present work is in keeping with the continuation of that work. The issues here concern the influence of the kind of noise source on the obtained trends. Indeed, if one no longer considers pink noise, i.e. broad-band noise, but various environmental noises, one may wonder what is happening to these trends. Furthermore, this study takes an interest in exploring if there are some mounting conditions more suitable than others for a given outdoor sound context.

2 Methodology

2.1 Binaural recordings

The study focusses on a few environmental noise sources, representative of noise annoyance felt by people in dwellings. The results presented in this communication correspond to the following noise sources:

- Source 1: airliner take-off (suburban area near Lyon St-Exupéry airport),
- Source 2: cars moving off at green light (urban area, Villeurbanne).

Sound sequences have been recorded by a dummy head (Neutrik Cortex MK2), placed in exposed rooms with the in situ window wide-open. The in situ recording configuration was determined to fit the simulation configuration [4], i.e. the dummy head was set in the room so that the theoretical horizontal angle of aperture from which outside is seen from the dummy head was the same as the one used for the calculated filters (see figure 1).

Two samples 4 seconds in length corresponding to the studied environmental noise sources were extracted from these sequences. Time-frequency analysis of these samples is proposed in paragraph 3.1.1.

2.2 Stimuli

Mounting conditions of a 4 mm thick glass plate in its frame have been studied. In practice, they correspond to different kinds of lateral blocks whose position, size, stiffness and damping characteristics may vary. Five cases were retained: two cases with continuous sealing joints (flexible or rigid ones), two cases with localized
blocks made up of wood or viscoelastic material and one case with continuous blocks in wood. As two frames (French frame and tilt-and-turn frame) were considered, 10 filters were actually studied. Modelling of the mounting conditions is described in paper [4].

In the framework of our study, the impulse response of each filter has been achieved using Inverse Fast Fourier Transform from acoustic pressure spectra previously calculated, for a white noise excitation, at two receiving points corresponding to the ear position of a listener. Then, transmitted environmental noises, i.e. noises filtered by the modelled glass plate, have been obtained by convoluting the environmental noise sample to the impulse response of each filter. A correction filter was actually applied to the transmitted noises to take into account the inverse transfer function of the headphones used for the sound restitution in the listening tests.

2.3 Listening tests

The listening tests took place in a quiet room. Stimuli have been submitted by pairs through headphones (Sennheiser HD600) to 18 trained subjects aged from 20 to 55. They were asked to evaluate the dissimilarity between stimuli on a seven category numeric scale with verbal label at the end points "very similar" and "very different"; they were also asked to indicate for each pair which stimulus they preferred. The subjects could listen to each pair of stimuli as often as they wanted to. All the subject have performed two separate listening tests, each one made up of 10 filtered environmental noises corresponding to one of the environmental noise samples filtered by the thin glass plate with varying mounting conditions (Cf. section 2.2.). The duration of each test did not exceed 15 minutes.

For each test, a multidimensional scaling analysis was run on the dissimilarity data to get the perceptual space with the perceived distances between stimuli. Analysis of correlations between coordinates of stimuli along the perceptual dimensions and metrics was performed in order to identify the perceptual attributes of the transmitted noises in accord with a close listening. Preference scores versus stimuli were also computed from expressed preference judgments according to the law of comparative judgment [5]. Coefficient of consistence was used to eliminate subjects' answers with too many transitivity errors. Analysis of correlations between preference scores and metrics was also carried out so that we could examine which perceptual attributes of the transmitted noises affected subjects' preference judgments. The relevant metrics were used to build models of perceived distances and preference scores. For both, coordinates of stimuli in perceptual space and preference scores, 95% confidence interval was calculated using the bootstrap technique [6] with 250 replications.

3 Results

3.1 Physical analysis ...

3.1.1 Environmental noise samples

A time-frequency analysis was run on the two environmental noise samples to emphasize the main characteristics of the acoustic signals, before being filtered. Figure 2 shows the spectrograms for both samples. Sample 1 corresponding to airliner take-off noise is rich in a large low/medium frequency domain (0-800 Hz). A low-frequency component notably emerges at 150 Hz. Sample 2 corresponding to cars moving off noise is a very low-frequency noise (0-125 Hz) with an important emergent component around 70 Hz. Sound pressure levels rise in the second part of the sample, corresponding to the acceleration phase of the vehicles.

3.1.2 Transmission filters

Figure 3 shows the transmission loss spectra for the different filters (considering tilt-and-turn frame only). The main effect of an increase in the stiffness of lateral continuous blocks can be seen on figure 3.a: the resonant frequencies of the overall structure are shifted to the upper frequencies. This shift turns out to be quite important (90 Hz) when passing from flexible sealing joints to rigid ones. Figure 3.b shows that the behaviour of a glass plate mounted in its window frame with localized blocks (made up of wood or viscoelastic material) comes near to the one of a glass plate mounted with continuous rigid sealing joints.
3.2 ... and coupling with auditory evaluation

Figure 4.a shows the two-dimension perceptual space of stimuli when aircraft noise was transmitted through the window with various glazing mounting conditions. The number of dimensions was determined using a Monte Carlo procedure. Dimension 1 is correlated with the specific loudness in Bark 2 ($r^2 = 0.95, \alpha < 0.001$). Three groups of stimuli have appeared along this dimension; a first group comprises the noises corresponding to the mountings with continuous flexible sealing joints; a second one comprising the noises transmitted through windows mounted with localized blocks and a last group comprises the noises corresponding to the mountings with continuous rigid blocks (rigid sealing joints and wood blocks). Dimension 2 is correlated with the specific loudness in Bark 5 ($r^2 = 0.62, \alpha < 0.007$). The great variation of specific loudness in Bark 2 has appeared sufficient to explain the preference scores ($r^2 = 0.93, \alpha < 0.001$). The obtained ranking (see figure 4.b) shows that the aircraft noises transmitted through glazing mounted with continuous rigid blocks were not at all appreciated. These noises are those whose perceived low-frequency content (i.e. specific loudness in Bark 2) is
higher; this results from the fact that the first resonance of the structure and the low-frequency component of the noise source match each other. This aspect underlines the weakness of the weighted sound reduction index $R_w$ used to quantify acoustic performance of building structures, calculated from 100 to 3150 Hz (see the EN ISO standard 717-1). On the contrary, the noises with poorer low-frequency content were preferred. They correspond to aircraft noise transmitted through glasses mounted with flexible sealing joints whose first resonance occurs below the low-frequency components of the noise source.

Stimuli corresponding to transmitted urban traffic noise have been scaled in a one-dimension perceptual space after a dimensionality investigation (see figure 5.a). This single dimension is correlated with a combination of sharpness and loudness ($R^2 = 0.96$, $\alpha < 0.001$). The contribution of sharpness to the distance model is important (around 85%). Three groups have been formed along the perceptual dimension; a first group includes the noises corresponding to the mountings with continuous wood blocks; a second one includes the noises corresponding to the mountings with localized blocks and continuous rigid sealing joints and a last one includes the noises corresponding to the mountings with continuous flexible sealing joints. The preference scores are correlated with the same psychoacoustic metrics, i.e. sharpness.

Figure 4: Results of the first listening test (transmitted aircraft noise).

Figure 5: Results of the second listening test (transmitted urban traffic noise).
and loudness ($R^2 = 0.98, \alpha < 0.001$). The contribution of sharpness to the preference model is still predominant (around 66%). The ranking of mountings shown on figure 5.b is different from the one obtained for the first test. The noises transmitted through windows mounted with continuous flexible sealing joints are this time not appreciated whereas the noises transmitted through windows with continuous rigid sealing joints or wood blocks are preferred. The first noises have very low values of the spectral centre of gravity, this feature has probably disturbed the listeners; the latter noises have medium values of the spectral centre of gravity, this relative "neutral" aspect has been more appreciated by the listeners. In comparison with these latter, the noises transmitted through windows with localized blocks are a little less appreciated because of their higher values of the spectral centre of gravity.

The calculated $R_w$ values, which are almost the same for all the mountings to within about 1 dB, are not representative of the preference ranking; this result goes for both tests.

4 Conclusions

This study has shown that two perceptual attributes at most have an effect on the auditory perception of the studied environmental noises transmitted through windows with varying mounting conditions. These attributes depend on the environmental noise source; nevertheless, most are linked to the frequency-content features of noises.

The obtained preference rankings of mountings are shown to be relevant on the kind of environmental noise source too. These rankings are also different from the one obtained by Faure et al. [4] for a broad-band noise (pink noise) transmitted through the glass plate, the mountings with localized blocks had been found to be the most appreciated by the subjects. The results of the present paper may underline the fact that it could exist a type of window more suited to a given outdoor noise exposure; this point has to be deeply investigated.

For all auditory evaluations, the $R_w$ values are not correlated with the preference scores; this point emphasizes the necessity to couple auditory evaluation to physical analysis to assess inner acoustic comfort.

References


