SOUND LEVELS AROUND BUILDINGS NEAR ROADWAYS

by

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ABSTRACT

This paper presents the results of preliminary measurements of the difference between the incident sound levels at the front and rear facades of suburban detached and semi-detached houses adjacent to major roadways. The measurements also yielded data on sound transmission through open windows and comparisons between the sound levels measured in open windows, at the surface of the building facade, and 2 m from the facade.

A preliminary series of measurements, now reported, is part of an ongoing effort to provide accurate prediction of the indoor sound levels in buildings affected by major transportation noise sources, in this case, highway traffic. The study involved three specific aspects of the problem:

1) the effect of reflections on the sound field near the exposed facade of a building;

2) the difference in the incident sound levels at exposed and sheltered facades of detached housing in the first row of buildings near a major highway;

3) the noise reduction characteristic of open windows.

As anticipated, the results demonstrated that simple, well-established approaches to these problems provide reasonable predictions.

Figure 1 illustrates the typical microphone positions used in taking simultaneous measurements at a number of positions inside and outside a building, including 2 m from the exposed facade, immediately adjacent (within 10 mm) to it, and inside and at the open windows of rooms on both the exposed and sheltered sides of the house. Metrosonics dB-301 logger units were used to measure the A-weighted equivalent sound level for 1-min intervals and store the data for up to 480 such intervals. By synchronizing the starting time of the six (or more) dB-301 units used at each site the difference in sound levels for any time interval could be readily obtained. Typically, data were logged for 80 to 100 min at each building, the indoor microphones being moved every 15 to 20 min to provide data for at least five positions and permit calculation of average room response.

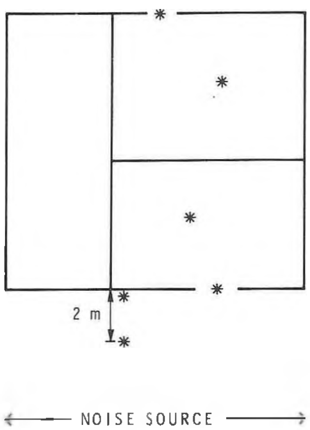

FIGURE 1

Schematic indication of typical microphone positions (indicated by asterisks) in window openings and adjacent to the exposed facade

The 1-min intervals provide sufficient temporal smearing to average out most of the fluctuation associated with the passing of an individual noisy vehicle. On the other hand, the intervals are short enough to permit discarding data from any intervals during which specific extraneous noises contaminated the traffic noise data. For room characterization the room and window dimensions and reverberation time were also measured.

The incident Sound Pressure Level (SPL) at the facade was generally used as the reference level. It was chosen because it is the incident SPL predicted by most traffic and aircraft noise models or measured on a site before buildings are constructed. It is important to remember that in the presence of reflecting surfaces such as building facades the measured SPL depends on the combination of incident and reflected sound fields. Before discussing the data, some of the basic features of the sound field near a reflecting surface should be reviewed.

The problem was treated particularly clearly by Waterhouse in the context of sound fields near the surfaces of a reverberation room.[1] Figure 2(a) shows his results for random incidence. At the surface the SPL is increased by 6 dB relative to the incident level because the combination of incident and reflected waves of the same amplitude and phase simply doubles the pressure. Interference between the incident and reflected waves causes standing waves near the surface, but because the location of their extrema depends on the angle of incidence, combining the incoherent contributions from different angles causes these fluctuations to average out; for distances $\sim$1 or 2 wavelengths from the wall the SPL increase tends to the 3 dB associated with doubling the energy. The second curve in Fig. 2(a) shows the similar results expected for a line source (note that the variations in SPL

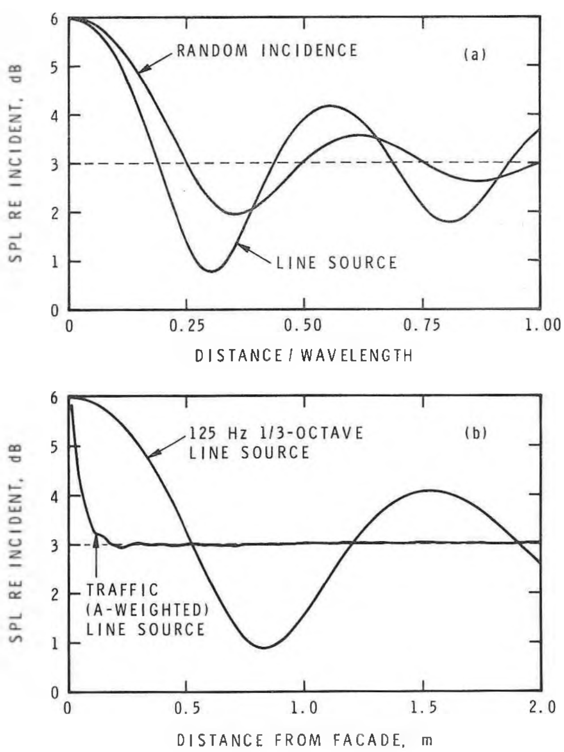

FIGURE 2

Sound pressure level near a reflecting surface for various source geometries and spectra with distance from the surface are larger). The curves shown in Fig. 2(a) are for a pure tone, but virtually identical results apply for a 1/3-octave band; with increasing band width the maxima and minima are reduced because the extrema are located at different positions for each frequency.

In Fig. 2(b) the calculated SPL for a line source parallel to a reflecting plane is shown as a function of distance from the surface (in metres). For individual third octave bands the SPL 2 m from the facade may deviate appreciably from 3 dB above the incident level (especially at low frequencies), but for A-weighted traffic noise the observed SPL should be very close to 3 dB above the incident level for distances of more than about 0.2 m. For distances up to ∿10 mm from the surface the SPL increase should be within 0.1 dB of the 6 dB pressure doubling. These predicted increases of 6 dB and 3 dB are appropriate for a rigid, perfectly reflecting surface; sound absorption by materials such as window glass or wood siding could reduce the increase by as much as half a decibel.

Although the incident SPL seems to be the appropriate reference level for this sort of study, there is no convenient way to measure it directly; directional microphones would distort the relative contributions from different parts of the line source and absorptive treatment of each facade to eliminate reflections over the relevant frequency range (60 - 5000 Hz) is not really practical. Measurements in a room with an open window can be used, however, to obtain a reasonable estimate. If the room's absorption (including the window opening) is not too large, the sound field in the room can be described fairly accurately as the combination of a reverberant field plus a direct field from the sound incident on the window opening. In the window opening the measured sound level (L_{WINDOW}) is dominated by the incident sound (L_{INC}), but the reverberant sound field (L_{ROOM}) is not insignificant. Using the equation

$$L_{INC} = 10 \log [\text{antilog } (L_{WINDOW}/10) - 0.5 \text{ antilog } (L_{ROOM}/10)] \qquad (1)$$

the incident SPL can readily be calculated. To the extent that one may ignore diffraction at the window opening and treat the incident and reverberant fields as uncorrelated, this should provide a reasonable measure of the incident sound level.

The data obtained in the window openings and the central area of the rooms were processed in this way to obtain the incident SPL. These values were then compared with the corresponding data for microphones immediately adjacent to the facade (Fig. 3). The mean difference of 5.6 dB is in quite good agreement with the expected increase of 6 dB. There is some scatter, but it is to be expected for several reasons:

1) the 1 dB resolution limit of the measuring units and the comparable calibration uncertainty would be expected to introduce scatter ∿ ±1 dB;

2) synchronization of the time intervals was imperfect (up to ∿ 5 s in some cases) and the effect of brief, loud events could fall in nominally different time intervals for the two units being compared;

3) interference effects associated with the finite, somewhat irregular facades and diffraction at the window opening could cause real deviations from the simple model used;

4) occasional extraneous noises.

Obviously this is not a precise test of the predicted pressure doubling, but it

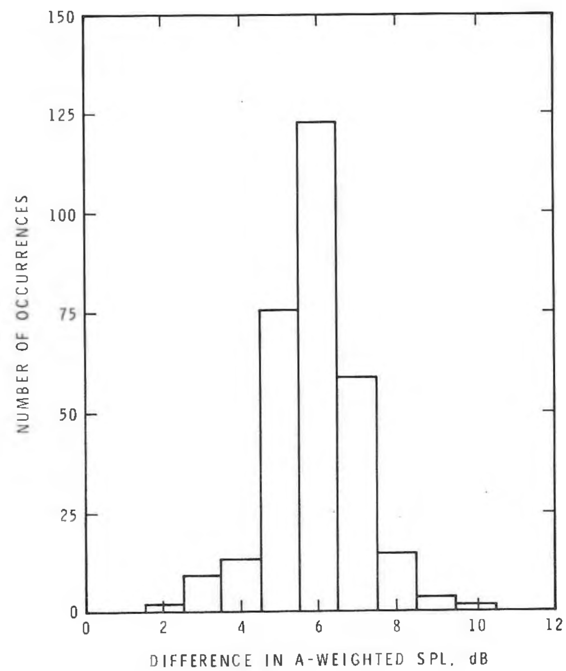

FIGURE 3

Difference between the measured sound level at the surface of the exposed facade and the incident sound level

does provide a fairly clear indication that the sound fields are basically consistent with simple physical expectations. The deviation from 6 dB is consistent with the expected effect of sound absorption by the window glass on which the microphones were mounted.

Similar agreement is found when the incident SPL is compared with the level 2 m from the facade (Fig. 4). The mean increase in the SPL relative to the incident level is 2.5 dB, in reasonable agreement with the expected value of 3 dB. Again, there is appreciable scatter, much of it presumably due to limited measurement accuracy and the effect of extraneous noises.

As already indicated, the procedure to measure the incident sound level required measurement of the sound level inside rooms with open windows and thus provided the data needed to assess sound transmission through open windows. Previous studies[2] indicated a wide range in the noise reduction associated with open windows; it seemed useful to assess the cause of these variations. Before examining the data, the expectations from a simple extension of the Transmission Loss (TL) measurement between two reverberant rooms[3] should be considered. In laboratory measurements the TL is determined from the difference between the reverberant sound levels in the source and receiving rooms (L_{SOURCE} and L_{REC} respectively) normalized to allow for the absorption (A) in the receiving room and the surface area (S) of the element transmitting the sound:

$$TL = L_{SOURCE} - L_{REC} + 10 \log [S/A]. \quad (2)$$

With this definition the TL corresponds to 10 log $(1/\tau)$, where τ is the ratio of transmitted to incident sound power. For an open window one expects all the sound power to pass through (i.e., $\tau = 1$ and TL = 0); experimental results generally agree with this for frequencies where the wavelength is appreciably less than the dimensions of the opening and diffraction can be ignored. For applications relating to exterior facades it is appropriate to consider the noise reduction relative to incident SPL at the test specimen rather than the reverberant level in the source room (L_{SOURCE}). For the reverberant source room $L_{INC} = L_{SOURCE} - 3$ dB, as shown by Waterhouse[1] and illustrated in Fig. 2a. Thus, the noise reduction relative to incident SPL when normalized like TL to allow for component area and receiving room absorption ($L_{INC} - L_{REC} + 10 \log [S/A]$) should correspond to TL - 3 dB; i.e., to -3 dB for an open window.

The actual measured noise reduction relative to the incident SPL (when normalized like laboratory TL data) is shown in Fig. 5. The mean value is -3.4 dB with a standard deviation of slightly less than 1 dB, in rather good agreement

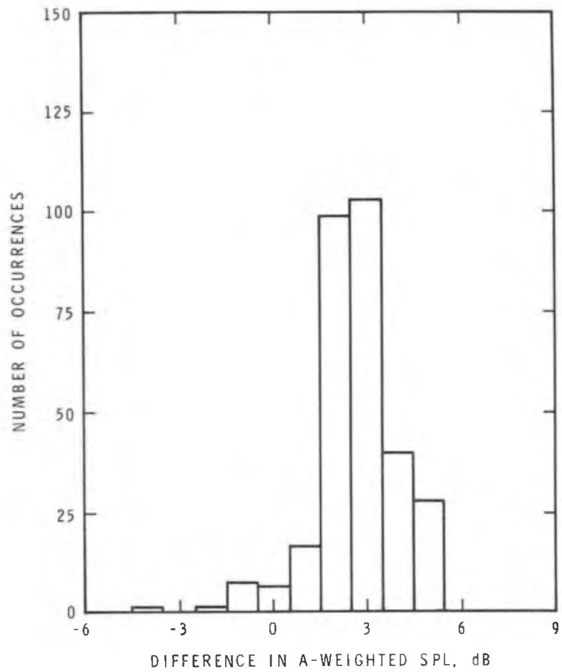

FIGURE 4

Difference between the measured sound level at 2 m from the exposed facade and the incident sound level

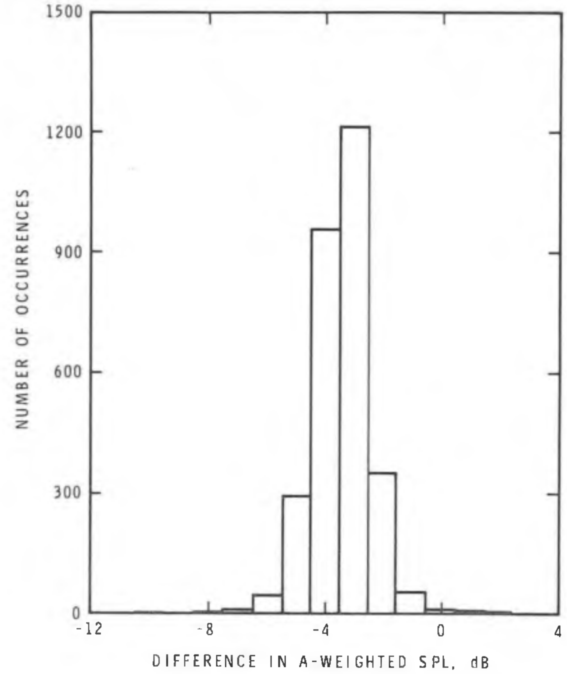

FIGURE 5

Noise reduction for open windows (relative to the incident sound level), normalized to the case where absorption (A) = open area (S)

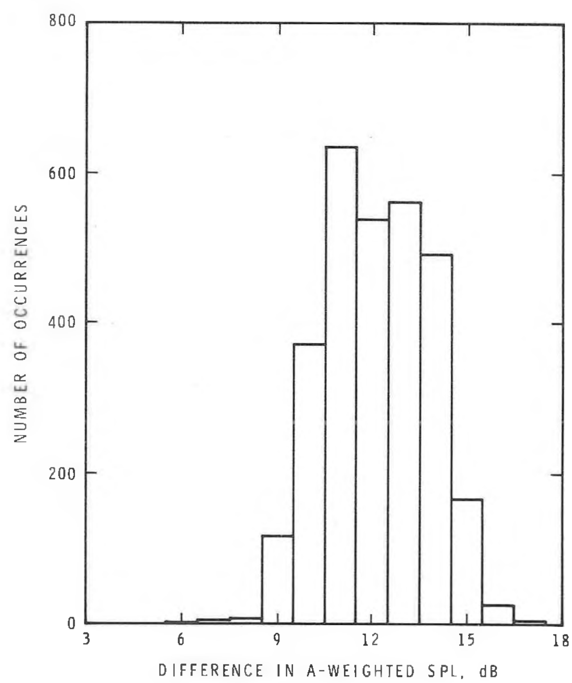

FIGURE 6

Noise reduction for open windows (relative to the incident sound level) when normalized to typical room conditions, as discussed in text

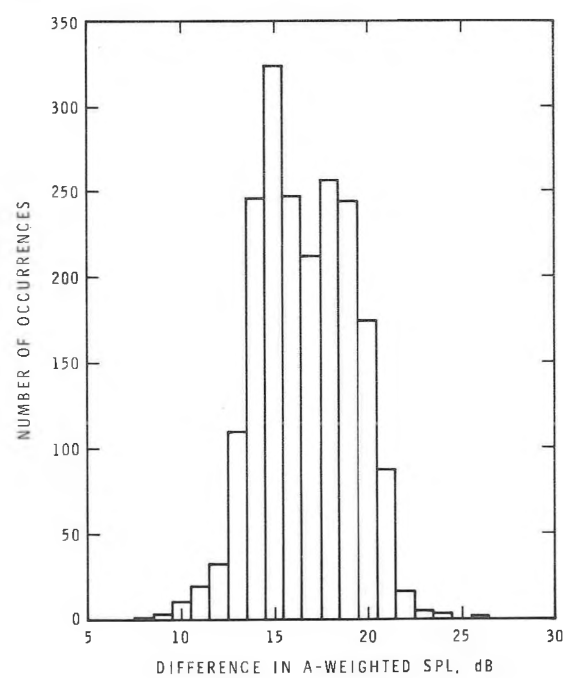

FIGURE 7

Difference between the incident sound levels measured at the exposed and sheltered facades of the houses with the expected value. Because of the rather large number of measurements (∿ 50 rooms) it is tempting to interpret this deviation from -3 dB as systematic. This is not unreasonable, as the increased sound transmission associated with diffraction at the lower frequencies[4] would tend to introduce this sort of shift in the results. The essential features, however, are the quite small scatter in data and the good agreement with the expected value of -3 dB. It should be noted that this shift of -3 dB (as well as corrections to allow for the difference between random incidence and a line source) must be allowed for in applying the laboratory data for any building element to predict indoor noise from an incident outdoor sound level.

Having established the sound transmission characteristics of the windows themselves, it is useful to examine their implications for typical indoor sound levels relative to the incident level. Figure 6 shows the same data re-normalized to assumed "typical" conditions: room reverberation time of 0.5 s and window opening of 3 ft^2. The latter was chosen because it is the required minimum opening for natural ventilation in Canada's National Building Code. The data in Fig. 6 show much more scatter than the data in Fig. 5 owing to the range of room size. Although the assumed window opening is a reasonable compromise between the discomforts of noise and heat, different occupants would obviously choose a range of openings and might furnish the room to give shorter or longer decay times. These individual variations would further broaden the range of expected noise reductions beyond that indicated in Fig. 6. It should be stressed, however, that for a given room and window a much smaller range (which can be readily calculated) would be expected.

Figure 7 presents the data pertinent to the original motivation for the study, the difference between the incident SPL at the exposed and sheltered facades of these houses. Clearly the data are of great concern in deciding on the noise control measures necessary to provide an acceptable indoor noise environment, particularly since bedrooms (where noise sensitivity tends to be greatest) are more likely to be on the sheltered side. For most of the cases studied here the noise level was 15 to 20 dB lower on the sheltered side. Because these houses were fairly large and closely spaced, however, and in most cases the buildings in the second row were smaller and more widely spaced, there are reasons to believe that the reflected sound power was somewhat less than would be encountered with a broader sample. Subsequent stages of the measurement program will try to establish data for a broader range of conditions. It is hoped that they will provide the basis for a simple empirical procedure for estimating noise at the sheltered wall, given simple data on size and spacing of nearby buildings. In the meanwhile, a reduction of 10 to 15 dB appears to give a fairly conservative estimate of the noise reaching the sheltered facade.

References

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