

# TRAFFIC NOISE TRANSMITTED INDOORS

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## 1 Introduction

In numerous countries, traffic noise is widely acknowledged as a highly disturbing form of pollution. Given that individuals spend a substantial portion of their day indoors, the impact of traffic noise perceived indoors is of considerable significance. To establish appropriate sound insulation requirements for buildings, it is essential to correlate subjective annoyance with objective ratings. This paper reviews the theoretical assumptions behind the regulations implemented by some countries and introduce the basic approach for the determination of acoustic performance of facades, utilizing Germany and Brazil as examples.

## 2 Sound reduction index in different environments

In order to better understand the reasoning behind the requirements in the different countries, the theory of the sound reduction for different sources will be touched upon shortly as by Kötz in [1]. The sound reduction index is defined as ten times the logarithm to the base ten of the ratio of incident sound power ( $P_1$ ) to the sound power transmitted to the receiving room ( $P_2$ ):

$$R = 10 \log \frac{P_1}{P_2} \quad (1)$$

The sound power is often determined by measurements of the sound pressure levels. However, depending on the existing incident sound field on the building element and on the location of the measurement, the relationship between sound power and sound pressure varies. In a diffuse field (d), when measuring at a distance from the source and boundaries, the relationship is as follows :

$$P_1(d) = \frac{1}{4} \frac{p_1^2 S}{\rho c} \quad (2)$$

$$P_2(d) = \frac{1}{4} \frac{p_2^2 A}{\rho c} \quad (3)$$

Inserting Eq.s 2 and 3 in 1 leads to the well known equation :

$$R = 10 \log \frac{p_1^2}{p_0^2} - 10 \log \frac{p_2^2}{p_0^2} + 10 \log \frac{S}{A}$$

$$R = L_1(d) - L_2(d) + 10 \log \frac{S}{A}$$

However, if the incident sound power stems from a line (l) or a point (p) source, while neglecting the geometric damping, the following relations to the sound pressure in the free field exist :

$$P_{1,f}(l) = \frac{2 p_{1,f}^2(l) S}{\pi \rho c} \cos \varphi \quad (4)$$

$$P_{1,f}(p) = \frac{p_{1,f}^2(p) S}{\rho c} \cos \vartheta \quad (5)$$

where  $\varphi$  is the levitation angle from the line source (street) towards the facade and  $\vartheta$  is the angle from the point source (loudspeaker) to the facade. The  $\frac{2}{\pi}$  stem from an integration over the full length of the line source. Note that the sound pressure in both cases it determined in the free field, meaning either in front of an open window or before the building is built.

Inserting Eq.s 4 and 5 with 3 in 1 leads to

$$\begin{aligned} R(d) &= L_1(d) - L_2(d) + 10 \log \frac{S}{A} \\ R(l) &= L_{1,f}(l) + 10 \log \frac{8 \cos \varphi}{\pi} - L_2(d) + 10 \log \frac{S}{A} \\ R(p) &= L_{1,f}(p) + 10 \log 4 \cos \vartheta - L_2(d) + 10 \log \frac{S}{A} \end{aligned}$$

If a fixed levitation angle  $\varphi$  of  $37^\circ$  and a point source angle of  $\vartheta$  of  $45^\circ$  are chosen the equations get simplified to :

$$\begin{aligned} R(d) &= L_1(d) - L_2(d) + 10 \log \frac{S}{A} \\ R(l) &= L_{1,f}(l) + 3 - L_2(d) + 10 \log \frac{S}{A} \quad (6) \\ R(p) &= L_{1,f}(p) + 4.5 - L_2(d) + 10 \log \frac{S}{A} \end{aligned}$$

In other words, if sound pressure measurements are made in the free field for a line or point source, 3 dB or 4.5 dB must be added to the measured sound pressure levels respectively, as can be found in ISO 16283-3 [2].

Furthermore, if measurements are not carried out in the free field, e.g. 0.5 m in front of the open window, but on the facade surface itself ( $L_{1,s}$ ) or 2 m away from the ‘‘closed’’ facade ( $L_{1,2m}$ ), 6 dB or 3 dB must be subtracted from the level, due to the constructive superposition of the waves. The 3 dB at 2 m distance is just a approximation. The actual values could be higher or lower depending on the frequency, but on average fit. Excluding the receiving room components ( $L_2(\text{diff}) + 10 \log \frac{S}{A}$ ) this all can be summarized in Table 1.

For calculations using the standardized level difference  $D_{nT}$  the following correction factor  $C_D = 10 \log(0.32V/S)$  has to be added to the sound reduction index,  $D_{nT} = R + C_D$ ,

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	line	point
free field	$L_{1,f}(\text{line}) + 3$	$L_{1,f}(\text{point}) + 4.5$
2 m	$L_{1,2m}(\text{line}) + 0$	$L_{1,2m}(\text{point}) + 1.5$
on surface	$L_{1,s}(\text{line}) - 3$	$L_{1,s}(\text{point}) - 1.5$

**TABLE 1** – Summary of correction to measured incident sound pressure levels relative to source type (line or point) and measurement location (free field, 2 m, on surface).

where  $V$  and  $S$  are the room volume and facade surface respectively. Note if the room behind the facade has a depth larger than 3 m  $D_{nT}$  is larger than  $R$  because the the sound power gets “diluted” in the larger room. All of these theories can also be applied to the weighted and apparent sound reduction and level differences measured at the various locations.

### 3 Outdoor-Indoor Requirements

As most, the few countries presented here (Germany and Brazil) base their requirements on these theoretical assumptions. The requirements are defined in DIN 4109 [3] in Germany and in ABNT NBR 15575-4 :2021 [4] for Brazil. In both countries, the requirements for sound insulation properties of the facade depends on the external noise levels. In Brazil, the requirements apply for bedrooms, whereas in Germany requirement for other room types also exist.

To be more specific, Brazil uses the weighted standardized level difference determined 2 m in front of the facade  $D_{2m,nT,w}$ , whereas Germany uses the apparent weighted standardized level difference determined in the free field  $D'_{nT,w}$  and then adds 3 dB. This is done indirectly by assuming a room height of 2.5 m and reformulating  $10 \log(0.32V/S)$  to  $10 \log(0.8S_g/S)$ , where  $S$  and  $S_g$  are the surface of the facade and floor respectively.

For traffic noise both countries use the eq. 6 for line sources, yet not frequency dependent, but as weighted single number quantities. Here shown for Germany.

$$D'_{nT,w} = \left( L_{1,f}(l) + 3 - L_2(d) + 10 \log \frac{S}{A} + C_D \right)_w \quad (7)$$

By neglecting the latter terms this converts to

$$D'_{nT,w} = (L_{1,f}(l) + 3 - L_2(d))_w, \quad (8)$$

which means if a specific indoor level ( $L_2$ ) is to be achieved and an incident level of  $L_{1,f}(l) + 3$  exists, the required  $D_{nT,w}$  or  $D_{2m,nT,w}$  can be determined.

In both countries equivalent incident levels are calculated for a day time (6/7am to 10pm) and night time (10pm to 6/7am) duration. The Brazilian day starts the hour later. In Germany the day level is used if the night level is more than 10 dB lower, otherwise the night level plus 10 dB is used (yet only for bedrooms) as the incident level. In Brazil, the higher level between day time or night time is to be used.

In Brazil the maximum indoor level  $L_2$  is 40, whereas in Germany it ranges from 25 dB to 30 dB, depending on if it is a hospital bedroom (25), common room (30) or an office (35). In Germany the required apparent weighted sound

reduction index ( $R'_{w}$ ) can be determined from this equation linearly. Also, if the resulting requirement is below 40 dB the flanking sound transmission does not have to be taken into account. Furthermore, the minimum requirement for  $R'_{w}$  is 30 dB to ensure other exterior noises to not disturb. In Brazil the incident levels are defined in three classes separated by steps of 5 dB each leading to a required  $D_{2m,nT,w}$ .

### 4 Past and current projects

An investigation in 2021 by Meier [5] led to the conclusion that the spectrum adaption terms  $C$  (traffic outside the city) and  $C_{tr}$  (traffic within the city) should be included in the requirements, but only need to start at 100 Hz.

Two listen test of outdoor noise transmitted to the indoors were recently carried out at the University of Applied Sciences Stuttgart (HFT) with the findings that the psychoacoustic loudness does not always correlate with the perceived annoyance [6] and that outdoor noises filtered frequency dependently through the facade result in the same perceived annoyance as the noises measured indoors [7]. An ongoing project at the HFT is using inexpensive noise monitor systems, developed by a citizen science group, to capture the outdoor noise spectra over several months to determine the importance of peak sound pressure levels.

In Canada, there is no requirements for acoustic performance of residential facades in its National Building Code (NBC). The National Research Council of Canada (NRC) is initiating a project to investigate the current relation of outdoor noise to indoor environmental quality in Canadian homes, including its effects on sleep quality, with the objective to establish guidance for facade performance and a future inclusion of this requirement in the NBC.

### 5 Summary

The basic assumptions for sound reduction of outdoor to indoor noise through a facade was presented, as well as examples of how they are applied in performance requirements.

### References

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