PROCEEDINGS of the
23rd International Congress on Acoustics

9 to 13 September 2019 in Aachen, Germany

Facade Sound Insulation as Protection to Outdoor Noise

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ABSTRACT

In recent years the acoustic qualification of buildings has gained more and more importance at international level. One of the central elements for determining the sound quality of houses is the insulation against external noise. In fact, many issues related to excessive noise in dwellings arise from their inclusion in noisy environments, or from their original surrounding environment, which has grown from silent to very noisy over the years. The main strategy to limit the noise inside the buildings is the façade insulation improvement. Regulatory requirements and classification schemes in Europe present a high degree of diversity. In particular, the approach to the façade insulation acoustic requirement adopted is very different in the various countries also because it is closely related to the outdoor environmental noise. The main issues related to the façade sound insulation are investigated with particular focus to the choice of the descriptors, the evaluation methods and their reproducibility. The latter aspect is the more difficult to evaluate.

Keywords: Façade Sound Insulation, Outdoor Noise, Acoustic Classification

1. INTRODUCTION

One of the central elements for determining the sound quality of houses is the insulation against external noise. In fact, many issues related to excessive noise in dwellings arise from their inclusion in noisy environments (1), or from their original surrounding environment, which has grown from silent to very noisy over the years. The main strategy to limit the noise inside the buildings is the façade insulation improvement (2).

The sound insulation of the façade can be evaluated according to different procedures; in general the related requirements are divided into two main categories, the one relating to the building elements performance (global facade or single element of facade), the second relating to the indoor sound level. An overview of the different parameters and classification schemes in Europe is given in section 2. The many difference of these parameters, also from the metrological point of view, implies first of all the understanding of protection degree needed against the outdoor noise. In fact, to guarantee indoor acoustic comfort, it is essential to understand the relationship between the environmental noise surrounding the building and the degree of the acoustic insulation needed for the facade. In particular, it is useful to correlate the external noise determined according to the European Noise Directive (END) (3) with the limit values for the acoustic classification of buildings. This is a well-known issue considering the ISO work for a new standard on building acoustic classification (4).

Critical aspects of the evaluation methods for the external level (L_{den}) have been dealt with several studies; Gaja *et al.* (5) have studied the problem of the external noise sampling, to determine an equivalent level over 24-h that is representative of the annual equivalent level. Brambilla *et al.* (6) have dealt with the issue of assessing the accuracy of a short-term sampling to estimate both the hourly L_{Aeq} and the day and night values.

Furthermore, considering that the END admits that individual countries may define the time periods differently, it is important to establish the correlations between L_{den} values of the END and the ones according to the needs of each government.

In Italy, for example, Zambon *et al.* (7) analyzed the procedures for the conversion of day and night values to L_{den} values and the descriptive statistics of the differences between the L_{den} level of the END and the Italian one.

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Finally, the problem of measuring the indoor level ($L_{den,\ indoor}$) still needs to be extensively studied, especially with reference to the microphone positions.

In this work the preliminary results of a study carried out at the ITC-CNR laboratories on the correlation between the sound insulation of the facade, the environmental noise and the level $L_{den,indoor}$ are reported,.

2. Acoustic requirements for facades

The facade sound insulation is evaluated in very different ways in European countries. An overview including façade sound insulation is summarized in Table 1 (8), where regulatory requirements are split into two main categories, the first is related to the performance of the building (façade sound insulation), the latter to the indoor sound level. The comparison of different European performance descriptors and the influence of acoustic and non-acoustic parameters, has been studied by Scamoni and Scrosati (9) and Masovic *et al.* (10) (11).

The façade sound insulation descriptors may be divided into two main categories: the former, including $D_{nT,w}$, and R_w expressing the performance (sound insulation of façade) directly, the latter, including the indoor sound level, expressing it indirectly.

Table 1 – Overview of facade sound insulation descriptors of 18 European countries

Requirement's Typology	N° countries	Measured quantity	
		Performance of the building facade	Indoor sound level
Façade requirement	11	$D_{2m,nT,w}$, $D_{2m,nT,w} + C_{tr}$ Element façade $R'w$, Rw	
Mixed	1	Element facade R'_w, R_w and $L_{A,eq}$ day and night	
Internal level requirement	6		$L_{A,eq}$ day and night L_{den} L_{pA24h}, L_{pAFmax}

Note: overview information only. Detailed requirements and conditions are found in the building codes of the different countries.

2.1 L_{den} and façade sound insulation

An example on how to correlate the limit values of external noise level with the façade sound insulation limit values can be found in an ongoing ISO work (4) for a new standard on building acoustic classification. In this proposal, the sound insulation of buildings against exterior noise is described by the $D_{nT,A,tr}$ (=$D_{2m,nT,w} + C_{tr}$) indicator, with the class limit depending on the noise level of the relevant outdoor source, itself described by the L_{den} indicator as defined in ISO 1996-1 (12) and determined in accordance with ISO 1996-2 (13).

The formula proposed to validate the correlation between sound insulation of façade and exterior noise level is expressed by the Equation 1:

$$D_{2m,nT,50} = L_{den} + 3 - L_{den,indoor} \qquad (1)$$

where $D_{2m,nT,50}$ is given by the Equation 2:

$$D_{2m,nT,50} = D_{2m,nT} + C_{tr,50-3150} \qquad (2)$$

where $D_{2m,nT}$ is the standardized level difference defined in ISO 16283-3 (14);

$C_{tr,50-3150}$ is the adaptation term as defined in ISO 717-1 (15);

$L_{den,\ indoor}$ is the indoor day - evening - night - weighted sound pressure level, with the appropriate weighting for the day, evening and night period, in the frequency range from 50 to 5000 Hz, as defined in the END for the L_{den} descriptor.

To evaluate the consistency of Equation 1, a study was carried out at the ITC-CNR laboratory, by using the average values of the standardized sound insulation, evaluated in the extended frequency range (50-3150 Hz and 50-5000 Hz), within a Round Robin Test (RRT) carried out on the same facade used for this comparative study (16).

3. EVALUATION METHODS

To address the aspects related to the position of the external microphone in relation to the surface of the façade (with the consequent effects of sound reflection) and in relation to the position normally adopted for standardized level difference measurements of the façade, the level L_{den} of the external noise was measured simultaneously in 3 different points (Figure 1). A first measurement position used for measuring the acoustic insulation of the façade, at 2 m from the wall, 5.45 height m from the ground (corresponding to 1.5 m height with respect to the floor of the receiving room) and horizontally, in the center of the facade under examination is defined as (CH3). The second position (CH4) is located 1 m away on the horizontal center of the façade and 4 m height with respect to the ground, according to the prescriptions of ISO 1996-2 for the L_{den} measurement. The third point (CH2) is directly placed on the surface of the façade corresponding to the second measurement point; the microphone was placed on a square plastic slab 0.3 cm thick and 20 cm wide, fixed to the wall with screws.

Referring to the Law in force in Italy (DM 16/03/98 (17)), the indoor level, $L_{den,\ indoor}$ (CH1), was measured simultaneously with the external one L_{den}, at the height of 1.50 m from the floor, at a distance 1.50 m from the window and at least 1.00 m from any reflective surface in the room. The receiving unfurnished room has a volume about 40 m^3 and is located at the first floor of the experimental building of the ITC, and its façade, made of precast concrete, has an aluminum frame window with a 4/12/4 mm glazing. The measurements were carried out during 25 days, not all consecutive, in January, February and March 2016, to obtain a reasonably reliable estimate (5) of the L_{den} value which, by definition, should be measured over a period of one year. The considered year is the relevant year as regards the emission of sound and an average year as regards the meteorological circumstances. If the incident sound is measured, and the sound reflected by the facade is omitted, as a general rule, a 3 dB correction must be adopted. When the microphone is placed at a certain distance from a reflecting surface, provided that some given conditions are met, the direct and reflected sound is equally strong and when the frequency band considered is wide enough, the reflection causes a doubling of the energy of the direct sound field and a 3 dB increase in sound pressure level (ISO 1996-2) can be found. For both the CH3 and CH4 positions, the perpendicular distance of the microphone from the reflective surface of the façade allows to obtain a nominally increase of 3dB. The values measured directly on the surface of the façade correspond to a position in which an increase of 6 dB of sound pressure level of the incident sound is obtained ("free field" level).

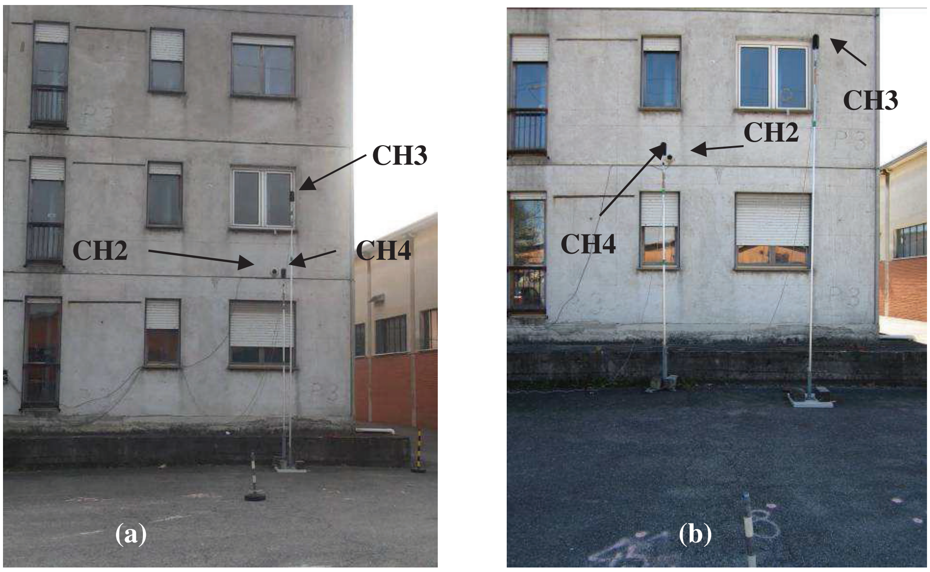

Figure 1 – Microphone location: (a) for the measurement of L_{den}; (b) for the edge effects evaluation.

Although ISO 1996-2 suggests that, for a particular receiver, the position of the microphone is related to that particular receiver, due to the edge effects in the frequency range from 125Hz to 4kHz, a further measurement of 46 h was made in April 2016. In that case, the CH4 and CH2 microphones were positioned at a distance *b* equal to 4m from the edge of the façade for the relation $b \geq 4d$ to be met, where *d* equal to 1m is the perpendicular distance of the microphone from the surface of the facade (CH4). The heights and distances of the two microphones from the surface of the facade have been kept constant (Figure 1 (b)).

3.1 L_{den}

Some measurements, performed in the absence of precipitation, fog and/or snow and with wind speed not exceeding 5 m/s, were performed for an overall duration of 25 days. The measurements were not all uninterrupted (about 5 weeks of which 2 including the weekend) and were carried out over three months from January to March 2016.

Table 2 shows the following values:

- the equivalent continuous sound pressure level L_{AeqT}, as defined in the Equation 3, relating to the entire measurement period;
- the $L_{den,2002}$ values, relating to the entire measurement period, for the day – evening - night periods defined in the END;
- the $L_{den,I}$ values, relating to the entire measurement period, for the day – evening - night periods defined in the Law in force in Italy (D. Lgs. 19 August 2005 n. 194).

where $L_{den,\ 2002}$ and $L_{den,I}$ are defined in Equation 4.

$$L_{AeqT} = 10\lg\left[\frac{1}{T}\int_T p_A^2(t)/\,p_0^2 dt\right] \tag{3}$$

$$L_{den} = 10\lg\left[\frac{d}{24}\times 10^{\frac{L_{day}}{10}} + \frac{e}{24}\times 10^{\frac{L_{evening}+5}{10}} + \frac{24-d-e}{24}\times 10^{\frac{L_{night}+10}{10}}\right] \tag{4}$$

Where:

- *d*, *e*, *n* are the number of hours of the day, of the evening and of the night respectively;
- L_{day} is the A-weighted equivalent continuous sound pressure level when the reference time interval is the day (dB);
- $L_{evening}$ is the A-weighted equivalent continuous sound pressure level when the reference time interval is the evening (dB);
- L_{night} is the A-weighted equivalent continuous sound pressure level when the reference time interval is the night (dB);

With the following time intervals:

- Default values according to END: the day is 12 hours (07.00-19.00), the evening is 4 hours (19.00-23.00) and the night is 8 hours (11.00-07.00);
- Values according to the Law in force in Italy: the day is 14 hours (06.00-20.00), the evening is 2 hours (20.00-22.00) and the night is 8 hours (22.00-06.00);

The L_{den} values reported in Table 2 did not include the 3dB correction, as they were used to verify the validity of Equation 1 (as a difference between the two levels), where the term +3 is used to cancel the effects of this correction.

Table 3 shows the L_{AeqT} values of external microphone positions, to assess the edge effects (Figure 1 (b)). The reference time is 46h, and the effects are negligible, as can be seen from the comparison with the L_{AeqT} values in Table 2.

Table 2 – L_{AeqT}, $L_{den,\ 2002}$ (END) and $L_{den,\ I}$ (Italian Law) assessed over the entire measurement period of approximately 25 days. (L_{den} values without the 3dB correction)

Microphone position	L_{AeqT} , dB	$L_{den,\ 2002}$, dB	$L_{den,\ I}$, dB
CH1	32.2	31.3	31.2
CH2	61.4	59.6	60.5
CH3	58.3	56.7	57.5
CH4	58.6	56.8	57.6

Table 3 – L_{AeqT}, over the entire measurement period (46h) to evaluate the edge effects.

Microphone position	L_{AeqT} , dB
CH2(b)	60.9
CH3(b=a)	58.5
CH3(b)	58.3

3.2 $D_{2m,nT,w}$ comparison

Table 4 shows the average value (average of 8 laboratories, each of which performed 5 repetitions for 40 measurements total) and the *in situ* standard deviation, obtained in the facade RRT (16), for the façade under study, according to the scheme in Figure 2. The measurements were carried out according to the prescriptions of ISO 16283-3, in particular, as the room volume is approximately 40 m^3, it was possible to make a comparison between the default procedure and the so-called "low-frequency procedure". Considering that the $L_{den,\ indoor}$ measurements were carried out in only one point of the room and not in the corners, it is more appropriate to apply Equation 1 to the results obtained with the default procedure, as shown in Table 4.

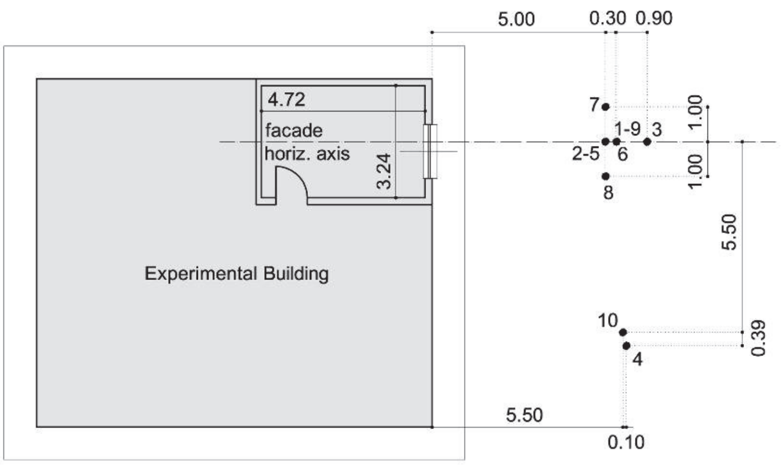

Figure 2 –Sound source position of each laboratory participating in the façade RRT (16)

Table 4 – Average values (5 repetitions for each of the 8 laboratories) of the RRT (16) and the corresponding *in situ* standard deviation (s_{situ}). The subscript "01" indicates that the descriptors were calculated in steps of 0.1 dB, or with rounding to 0.1 dB in the case of indices with the sum of the spectrum adaptation terms.

Descriptior (SNQ)	Average,dB	s_{situ},dB
$D_{ls,2m,nT,w01}$	40.0	0.7
$D_{ls,2m,nT,w01}+C_{tr(50-3150)}$	34.7	1.0
$D_{ls,2m,nT,w01}+C_{tr(50-5000)}$	34.7	1.0

As stated above, the measurements were carried out in 25 non-consecutive days (about 5 weeks). Gaja *et al.* (5) estimated for a similar period of time, 4 random weeks, a standard deviation equal to 0.81 dB. This standard deviation is comparable with the estimate of *in situ* standard deviation found for the façade sound insulation (see Table 4).

The value of $D_{2m,nT,50}$ was calculated by applying Equation 1 to the values of Table 2, both for the microphone position corresponding to the one used for the façade sound insulation measurements as per ISO 16283-3 (CH3) and the position corresponding to the "environmental" position, 4 m high and 1 m far from the façade (CH4). It was found that, considering $L_{den,2002}$, $D_{2m,nT,50}$ (CH3) was equal to 25.4 dB and $D_{2m,nT,50}$ (CH4) was equal to 25.5 dB.

By comparing these results with the average values of $D_{ls,2m,nT,w01}+C_{tr(50-3150/5000)}$ coming from the RRT, equal to 34.7 dB, a difference in the estimation of the façade sound insulation equal to 9.3÷9.2 dB was found.

Repeating the same calculation referring to the law in force in Italy (DM 16/03/98), $D_{2m,nT,50}$ is equal to 26.3 dB (CH3) and to 26.4 dB (CH4). Therefore, in this case, the difference with $D_{ls,2m,nT,w01}+C_{tr(50-3150/5000)}$ reduces to 8.4÷8.3dB. By applying the error propagation, this difference has the expanded uncertainty for the 90% confidence level for the two-sided test equal to 4.4 dB.

The sound field in the receiving room is not perfectly diffuse, in particular below the Schroeder frequency. Garai *et al.* (18) showed that for this room the Schroeder cut-off frequency is 400 Hz.

Figure 3 shows this behavior. Above the Schroeder frequency, all the differences taken into account in this study show the same trend. Below the Schroeder frequency in semi-diffuse field (down to 100Hz) and in non-diffuse field (down to 50 Hz) the trends are very different.

At the higher frequencies (4000 and 5000 Hz) the accuracy and precision of the measurements of $D_{2m,nT}$ depend on the position of the source and its directivity, as already stated in the reference (16). In a previous facade RRT (19), in which all the laboratories used the same source position, the accuracy of the results at high frequencies was much higher. This influence must also be analyzed in the case of an extended source.

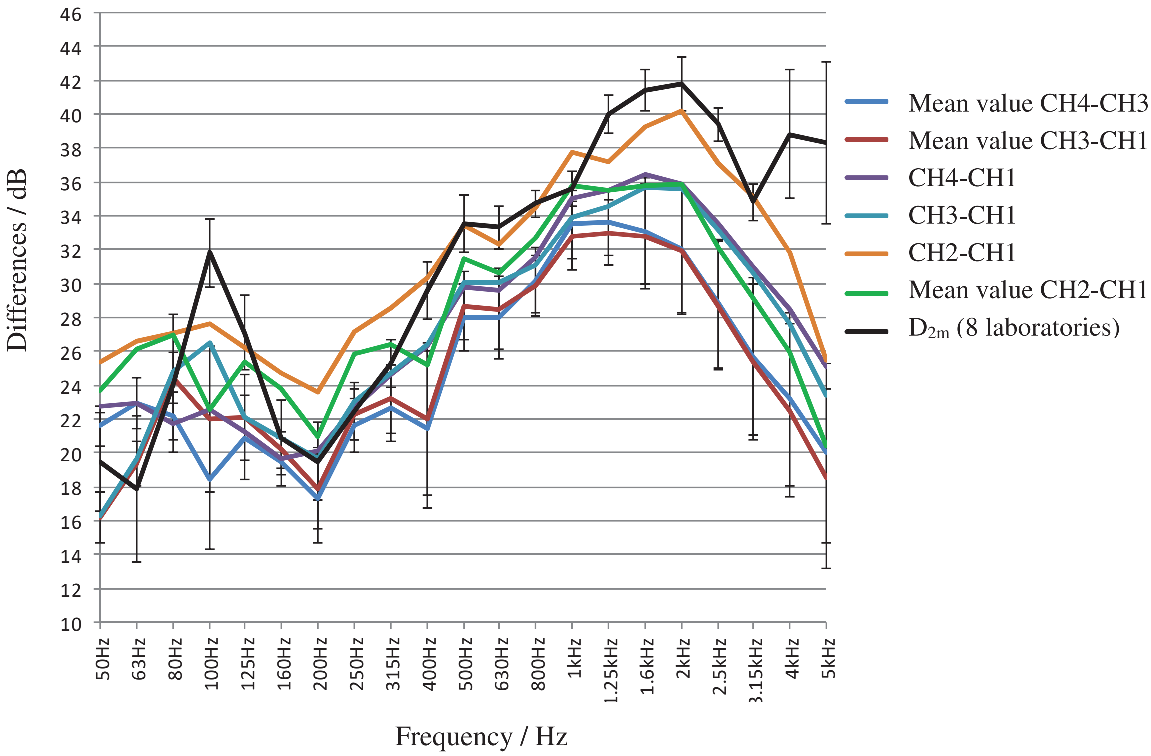

Figure 3 –Differences comparisons: 8 laboratoriesRRT average D_{2m}(black), with the error bars in terms of in situ standard deviation; mean value (time average over 25 days of measurement) of the differences between the measured values CH4-CH1 (blue), CH3-CH1 (red), and CH2-CH1 (green), with the error bars in terms of standard deviation of the mean; difference for a maximum value of the spectrum with hourly average CH4-CH1 (purple), CH3-CH1 (blue) and CH2-CH1 (orange).

4. CONCLUSIONS

The results of the research highlighted that the considered correlation between the noise level descriptor (L_{den} outdoor and indoor) and the façade sound insulation descriptor $D_{2m,nT}$ is not reliable.

The value of $D_{2m,\,nT,\,50}$ measured directly differs 8÷ 9 dB from the value calculated by applying this correlation, and using measured values of L_{den} and $L_{den,\,indoor}$. Although further verifications are necessary, based on a greater number of experimental data, obtained in different environmental situations, and such as to allow a more accurate statistical analysis, it does not seem appropriate to adopt this correlation as a procedure in order to classify the façade sound insulation requirement.

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