

Validation of EN 12354-1 prediction models by means of Intensity and Vibration measurement techniques in Spanish buildings involving flanking airborne sound transmission

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Flanking transmission in building structures can be estimated using the Intensity technique according to the method described in the standard EN 15186-2 Annex C. This can also be done by using Vibration measurement technique.

In situ conditions, the junctions of a room show different behaviours when compared to those obtained in laboratory. Measurements were performed to compare the results obtained by the pressure measurement procedure according to EN 140-4 and the prediction results obtained by the methods described in the standard EN 12354-1. Also the Intensity measurement technique was used to evaluate the contribution of each wall and flanking paths, which were compared with the results obtained by the Vibration measurements procedure. The main issue is to use the prediction models previously referred for validation to the particular Spanish buildings

1 Introduction

In building acoustics the contribution of flanking transmission in the sound reduction index has won new interest of study after the introduction of EN 12354-1 [1] and with it new quantity - Vibration Reduction Index K_{ij} . This number gives us the information related with a specific type of junction between structural elements in a building. Using this value it is possible during project phase a process calculation and as a result estimate the apparent sound reduction index with flanking contribution. Largely, the information contained in this standard was obtained by North European laboratories and the doubt of the correspondence to South European constructions has installed.

This work intends to verify if the general Spanish habitable buildings can be acoustically projected using materials characteristics and the information contained in literature EN 12354-1 [1]

The study was performed in a seventies University building but presenting construction similarity with nowadays buildings.

Were performed three measurement procedures for evaluate airborne apparent sound reduction index between two rooms separated by a single layer wall.

- Pressure method according to EN ISO 10140-4 [2];

- Intensity method according to EN 15186-2 [3];
- Vibrations velocity method not standardized.

This last method requires a mathematical model for calculating radiation efficiency, the model used was proposed by Rindell [4]

According to EN 12354-1 [1] and *in-situ* materials characteristics, was projected one apparent sound reduction index matching the separating element and two sound reduction indexes including all the flanking contribution.

2 Measurement place

The source room dimensions are 6,80x 9,70x3,01 [m] and a volume of 181 [m³]. The receiving room dimensions are 4,18x3,71x3,02 [m] and a volume of 43,8 [m³]. All lateral walls are built of bricks and finalized with a concrete (mortar or plaster) layer on each side, the total thickness is 115 [mm] with approximately 120 [Kg/m³]. The critical frequency is approximately 175 [Hz]. The ceiling is composed by beams, compression layer and finalized with a paving-tile on the superior part, with an overall thickness of about 370 [mm] and density of approximately 450 [Kg/m²] corresponding to a critical frequency less than 100 [Hz].

2.1 Type of junctions

The connections between the source room and the receiving room are simple rigid T junctions in vertical and horizontal connections.

The main transmission path or direct path is the separating element between the two rooms, the wall dimensions are 4,18x3,02 [m] corresponding to an area of 12,62 [m²] and a thickness of 115 [mm].

3 Measurements

3.1 Pressure method

The equipment used for the pressure measures was the dual-channel real time frequency analyzer B&K¹ type 2144 with an octahedral sound source, a sound level calibrator B&K type 4231 and a microphone B&K type 4190. The data were post-processed by the software B&K "Building acoustic program" WT9343 Ver.1.71 (1992).

Measurements were made using EN ISO 10140-4 procedures [2].

The sound pressure measured in the source room was used for Intensity and Vibrations calculations.

3.2 Intensity method

For the intensity measures, the same equipment was used as for the pressure method and additionally the sound intensity p-p probe B&K type 3520 modified to a more recent model, with sound intensity microphone pairs B&K type 4181. For the calibration procedure the sound intensity calibrator B&K type 3541 was used.

All the measurements were made in 1/3 octave bands, between 100 and 3.150 [Hz]. Measurement conditions must be satisfactory and in accordance with the requirements of the EN ISO 15186-2 [3] and EN ISO 9614-2 [5].

Measurement scans were of 1 minute each (maximum) and the surface was divided in 9 or 12 sub-areas, depending on the surface dimension.

The calculation of the sound reduction index R'_l for the separating element was done using the equation present in the EN ISO 15186-2 standard [3].

The apparent sound reduction index R'_l with the contribution of all the flanking walls is obtained by the equation (1) also present in the EN ISO 15186-2 [3] annex C. The Waterhouse correction factor K_c was not computed in the final results.

$$R'_l = \left[L_{p1} - 6 + 10 \log \left(\frac{S}{S_0} \right) \right] - 10 \log \left[\sum_j S_{M_j} 10^{\frac{\bar{L}_j}{10}} \right] + K_c \quad (1)$$

3.3 Vibration & radiation efficiency

The equipment used for vibration measurements was composed by a real-time analyzer B&K type 2144; two charge accelerometers of B&K. model type 4384. The accelerometers were placed onto the wall using bee wax. An accelerometer calibrator from B&K. model type 4294 was also used. The accelerometers were calibrated before each measurement using a reference acceleration of 10⁻⁶ [m/s²]. The measurement procedure for this vibration method used some of the criteria suggested in prEN ISO/DIS 10848-1 [6].

There are a total of 12 measurement positions, randomly distributed over the entire surfaces. The measurement time for each position was of 60 [s] and all the measures were taken in steady-state conditions. All data were acquired as acceleration values with the real-time analyzer and then post-processed to vibration velocities calculated with a reference velocity of 5x10⁻⁸ [m/s] using Microsoft ExcelTM sheet.

To compute the power level radiated by the surface the equation (2) developed by Cremer [7] was used.

$$L_{w_v} = L_v + 10 \log(S) + 10 \log(\sigma) \quad [dB] \quad (2)$$

Where S is the area of the surface and σ is the radiation efficiency. The radiation efficiency can be estimated for random incidence with the equation (3) given by Rindell [4]:

$$\sigma = \frac{1}{2} [0,20 + \log(k \cdot e)] \quad (3)$$

Where k is the wave number and e is a characteristic dimension of the surface and is determined from $e=4S/U$, where S is the area and U is the perimeter. This equation is independent from the critical frequency of the element.

The apparent sound reduction index R'_v for vibrations measures and for the separating element is calculated with the equation (4).

$$R'_v = \left[L_{p1} - 6 + 10 \log \left(\frac{S}{S_0} \right) \right] - L_{w_v} \quad (4)$$

¹ Brüel & Kjaer

Where L_{p1} is the sound level in the source room, S is the separating element area and S_0 is the reference area of 1 [m²].

The apparent sound reduction index R'_v , where all the flanking surfaces are added is obtained using equation (5), similar to the one used by the Intensity method, in this case without the Waterhouse correction factor K_c . For more information see Andrade [8]

$$R'_v = \left[L_{p1} - 6 + 10 \log \left(\frac{S}{S_0} \right) \right] - 10 \log \left[\sum_j S_{M_j} 10^{\frac{\bar{L}_j}{10}} \right] \quad (5)$$

4 Prediction calculus

4.1 Simplified model

The simplified model for structured borne transmission predicts the weighted sound reduction indices involved concerning EN 717-1 [9]. The weighted index is calculated in [dB] according the following equation (6):

$$R'_w = -10 \log \left[10^{\frac{R_{Dd,w}}{10}} + \sum_{F=f-1}^n 10^{\frac{R_{Ff,w}}{10}} + \sum_{f=1}^n 10^{\frac{R_{Df,w}}{10}} + \sum_{F=1}^n 10^{\frac{R_{Fd,w}}{10}} \right] \quad (6)$$

Where $R_{Dd,w}$ is the weighted sound reduction index for direct transmission, $R_{Ff,w}$ is the weighted flanking sound reduction index for transmission path Ff, $R_{Df,w}$ is the weighted flanking sound reduction index for transmission path Df, $R_{Fd,w}$ is the weighted flanking sound reduction index for transmission path Fd, all in [dB] and n is the flanking elements, usually 4. Due to the T type junctions the transmission path corresponding to R_{44} does not exist and was not summarized.

For each element the weighted sound reduction index was calculated using the mass law equation (7):

$$R_w = 37,51 \log \left(\frac{m'}{m_0} \right) - 42 \quad (7)$$

Where m' is the surface mass in [kg/m²].

The weighted flanking sound reduction indices are determined according to the following equation (8):

$$R_{D.f,w} = \frac{R_{s,w} + R_{f,w}}{2} + K_{D.f} + 10 \log \frac{S_s}{l_0 l_f} \quad (8)$$

Where R_s and R_f are the weighted sound reduction index for the separating element and flanking element, respectively. The S_s is the separating element surface area and l_f the junction length between the separating element and flanking element. The value K_{Df} is the vibration reduction index for the T junction correspondent, obtained from Annex E of EN 12354-1 [1].

4.2 Detailed model

The detailed model for structured borne transmission starts with calculating the sound reduction index for separating elements in 1/3 octave frequency bands according to EN 12354-1 [1] as shown in (9).

$$R'_w = -10 \log(\tau') \quad (9)$$

The total transmission factor τ' (10) can be divided into transmission factors related to each receiving room elements and systems involved in direct and indirect airborne transmission.

$$\tau' = \tau_d + \sum_{f=1}^n \tau_f + \sum_{e=1}^m \tau_e + \sum_{s=1}^k \tau_s \quad (10)$$

Where τ_d is the sound power ratio of radiated sound power by the common part of the separating element relative to incident radiated sound power on the common part of the separating element, it includes the paths Dd and Df and τ_f is the sound power ratio of the radiated sound power of a flanking element f in the receiving room relative to incident sound power on the common part of the separating element, it includes paths Ff and Df. The sound power related with indirect and direct sound power represented with suffices s and e , respectively was not summarized. The flanking paths can be easily understood using Figure 1.

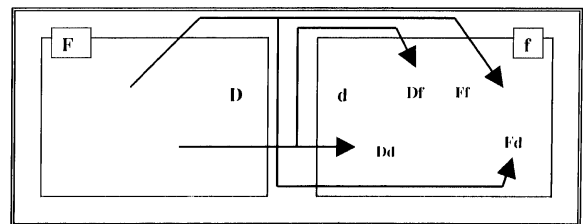


Figure 1 Sound transmission paths between two rooms

The sound reduction index of the separating element and the sound reduction index of the flanking elements were then computed using the algorithm explained in the annex B of EN 12354-1 [1] for monolithic elements in frequency bands. This calculus procedure involves several equations that can not be fully represented here, therefore only the main equations are written. The procedure depends on the critical frequency of our element and presents different equations for frequencies below, equal and higher values respecting the critical frequency.

As an example, τ is calculated by equation (11) for frequencies above the critical frequency.

$$\tau_d = \left(\frac{2\rho_0 c_0}{2\pi f m'} \right)^2 \frac{\pi f_c \sigma^2}{2f \eta_{tot}} \quad (11)$$

Where σ is the radiation factor for free bending waves, η_{tot} is the total loss factor and m' is the mass per unit area. The calculation steps of the algorithm are well explained in the Annex B of EN 12354-1 [1].

5 Results and conclusions

The results obtained are now presented and compared. The apparent sound reduction index calculated by two measured methods, Intensity and Vibration velocity, for the separating element and the correspondent prediction slope in one third octave bands are shown in Figure 2.

The correspondent weighted sound reduction indexes calculated in accordance with EN 717-1 [9] are expressed in [dB] on Table 1:

Table 1 – Separating element weighted SRI²

R'w
R'I_w 42 (-1;-4) by Intensity
R'v_w 41 (-1;-3) by Vibration Velocity
R'_w 39 (-1;-4) by Detailed Model
R'_w 43 (C, -1dB) by Simplified Model

Has can be seen the weighted sound reduction index for the separating element can be predicted in a more

secure way using the simplified model, rather than the detailed model. The results obtained by the Intensity method are assumed has being correct, to be inevitably sure it would be necessary to carry out Pressure measurements using shielding and unfortunately that was not possible.

The results obtained including the flanking transmission for the tested rooms, using the measured Pressure, Intensity and Velocity method in comparison with the prediction Detailed model of EN 12354-1 [1] can be seen in Figure 3 the slope obtained by the predicted detailed model assume a behaviour similar to those verified by *in situ* measurements, presenting the main differences at higher frequencies 2500 and 3150 [Hz] and in lower frequencies particularly at 250 and 315 [Hz].

The correspondent weighted sound reduction indexes including the flanking contribution are expressed in Table 2:

Table 2 – Overall weighted SRI

R'w
R'_w 39 (-1;-3) by Pressure
R'I_w 39 (-2;-5) by Intensity
R'v_w 39 (-1;-4) by Vibration Velocity
R'_w 39 (-2;-5) by Detailed Model
R'_w 41 (C, -1dB) by Simplified Model

The weighted sound reduction index obtained by *in situ* measurements is the same and the Detailed model presenting equal value, 39 [dB]. The simplified model gives a security plafond of 2 [dB], presenting 41 [dB].

Respecting the correction factors for pink noise and traffic noise is noticeable the same values presented by Intensity method and the Detailed model. The Vibration Velocity method and the Pressure method also present similar pink noise correction factors.

The main objective of this experimental work was the verification and applicability of the EN 12354-1, after this results is possible to conclude that the prediction models used [here](#) can be applied with good agreement to the Spanish constructions in the case of single layer elements.

Most certainly it is possible to enlarge this agreement to other type of elements used in construction, based in the same model.

² Sound Reduction Index

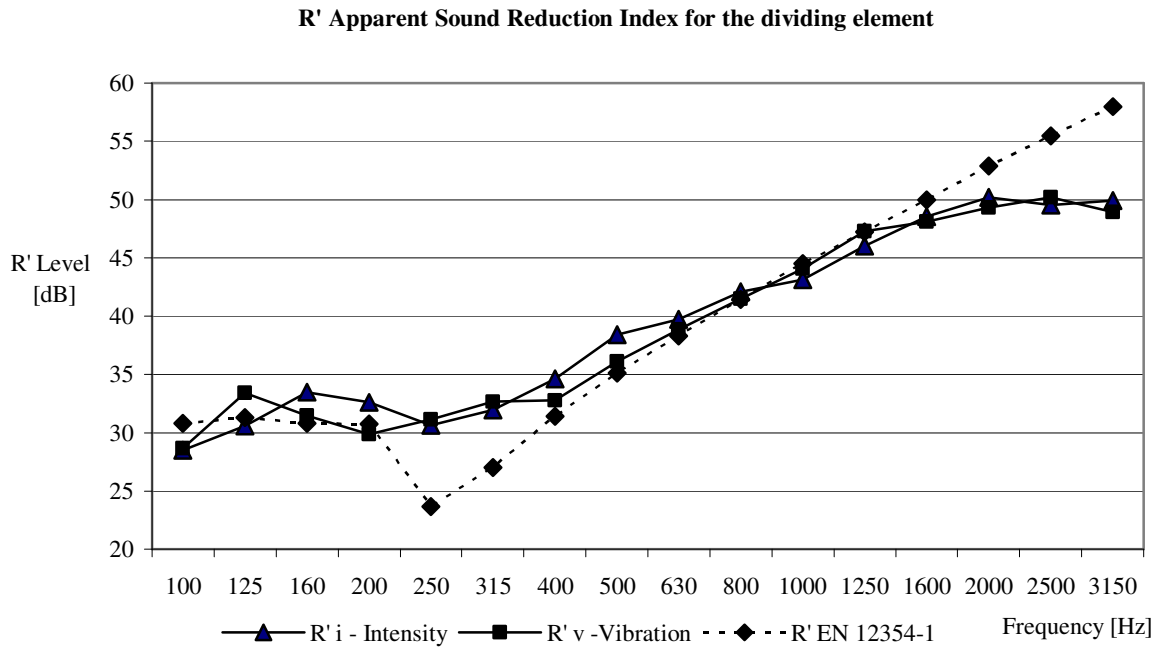


Figure 2

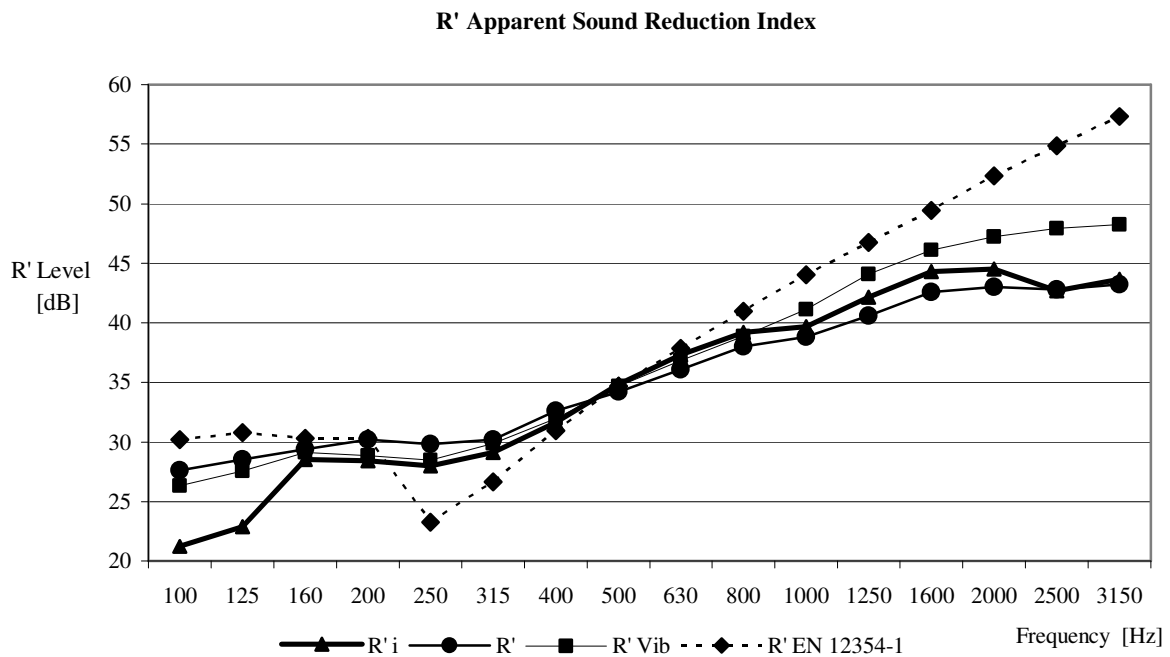


Figure 3

References

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