Study on the convenience of performing façade insulation measurements using the low-frequency procedure in rooms with a volume above 25 m^3

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Abstract

Part 3 of the ISO 16283 standard describes the procedure to determine the sound insulation of a façade. The procedure is applied to rooms with volumes ranging from 10 m^3 to 250 m^3 in the frequency range between 50 and 5000 Hz. For a volume of the receiving room above 25 m^3, it is not mandatory to use the low-frequency procedure for the bands octave of 50, 63 Hz and 80 Hz. It is enough that the sound source is capable of generating sufficient level from 50 Hz. In this work measurements have been carried out in rooms with a volume greater than 25 m^3 both using and not using the low-frequency procedure in order to answer the question of whether, although it is not mandatory, it is advisable to calculate the sound pressure level taking into account the maximum sound pressure value measured in the corners of the room.

Keywords: façade, acoustic insulation, low frequency

1 Introduction

In-situ sound insulation measurements must be carried out in a repeatable and reproducible manner to avoid legal concerns especially when the measurement results are close to the prescribed sound insulation limits. The low-frequency measurement procedures described in the ISO 140 series of standards did not yield good results [1]. Parts 4 and 7 of the ISO 140 series of standards, concerning the measurement of airborne and impact sound insulation, included annexes providing guidance on how to carry out measurements in the low frequency range, but the requirements were sometimes difficult to meet in confined spaces. However, ISO 140-5, on the measurement of airborne sound insulation of façades, did not include a similar annex, even though low frequency bands are often relevant in this case for many sources of environmental noise [2].

This point is revised in ISO 16283-3 [3], which deals with the measurement of sound insulation of façades and supersedes the former ISO 140-5. This standard describes a measurement method for the low-frequency range that must be used if the volume of the receiving room is less than 25 m^3. This volume (i.e., 25 m^3) was determined during the drafting of the standard, as it was necessary to identify a maximum volume to which the low frequency procedure should be applied. In the end, this volume was set at 25 m^3 although initially the low frequency procedure was set for volumes below 50 m^3.

The determination of this initial volume (i.e., 50 m^3) was based on the distribution of modes in rooms with small volumes and unfavorable dimensions, where at least one room dimension matches the wavelength and another one matches at least half of the wavelength of the central frequency of the lowest frequency band. On this basis, and taking into account that the lowest 1/3 octave band covered by the standards is 50 Hz, one of the room dimensions should at least be 6,88 m and the other 3,44 m. Considering these dimensions into account and given the fact that the height of an enclosure ranges between 2 and 2.3 m, the volume of the room needed to be at least 50 m^3 to avoid the use of the low-frequency method.

However, the use of this volume, calculated on physical principles, had some practical drawbacks, as most rooms in regular dwellings would be below 50 m^3, therefore requiring the constant use of the low-frequency procedure and significantly increasing the duration of the measurements. Consequently, the maximum volume of the enclosure was reduced from the originally planned 50 m^3 to half that, 25 m^3.

The low-frequency procedure, involving measurement in corners, is based on the fact that the sound field is not diffuse in regular and small enclosures. Hence, the aim of this method is to improve repeatability and reduce low-frequency uncertainty, which can have a direct impact on the comfort of the occupant of a small room, especially considering that it is common for people to sleep with their heads close to walls or even to a corner, where sound pressure levels tend to be significantly higher than in the central area of the room.

Although standardized, the low-frequency procedure still offers a number of unknowns that need to be addressed, especially considering that both the duration of a sound insulation measurement and its subsequent analysis increases significantly, which implies that an operator does not normally carry out measurements using the low-frequency procedure if the volume of the room is above 25 m3. Furthermore, in most countries, measurements for regulatory purposes are only required between the 1/3 octave bands of 100 and 3150 Hz [2].

Nevertheless, it is possible to find some literature on the use of the low-frequency measurement procedure. For example, regarding airborne sound insulation between rooms, it has been investigated how these low frequency procedures are affected by the type of excitation in the emitting room or by the presence of furniture in the receiving room [4]. With regard to façades, there are studies on measurements in timber-framed buildings [5] comparing the results of the default measurement and the measurement with the specific low-frequency procedure in rooms with a volume of less than 25 m^3. In these measurements, reference was made by taking the average value of the sound pressure level measured at five microphone positions in the central area of the room following the default procedure. Then, this reference value was compared with those obtained at the corners. It was found that the difference in sound pressure level when comparing the measurements in the different corners can be up to 10 dB for 1/3 octave bands below 500 Hz. This study also examined the influence of the microphone position in the corner, confirming the specifications of the standard.

In general, in Spain, the average floor area of single bedrooms ranges between 9 and 11 m^2. Considering that most local regulations set the minimum free height at 2.5 m, the volume of these rooms ranges between 22.5 and 27.5 m^3, which places a typical bedroom in an uncertain range for the application of the specific low-frequency method. In this paper, façade airborne sound insulation measurements have been carried out in the range between 50 and 5000 Hz in enclosures with a volume greater than 25 m^3 using both the default and the specific low-frequency procedures of ISO 16283-3:2016. The implications of employing the specific low-frequency procedure for the measurement of airborne sound insulation measurements in façades were analyzed. In addition, it was also analyzed how the single number quantity of sound insulation is affected by considering the average sound pressure level measured in the corners instead of the maximum value for the calculation of the level in the receiving room (L_2) for the 50, 63 and 80 Hz bands, as it is currently indicated in the ISO 16283-3:2016 standard.

In summary, significant differences could be found between the measurements using the two methods, with the sound insulation in the low-frequency bands being lower when the specific low-frequency procedure is included both in the measurement and the calculation of façade sound insulation.

2 Experimental setup

Measurements were carried out in three rooms, two located in traditionally built dwellings and the third in a dwelling built with shipping containers. The rooms in which the measurements were carried out were geometrically simple, being rectangular in all three cases.

All façades had Polyvinyl Chloride (PVC) framed windows. Table I shows the volume, the type of construction and the mean reverberation time of each of the three rooms, as well as the area of their window openings.

Table I. Description of the three (R1, R2 and R3) measured rooms, including their volume, construction type and mean reverberation time, as well as the area of their window opening.

Room	Volume (m^3)	Hollow area (m^2)	T_{20}(s)	Construction type
R1	29,0	4,4	0,56	Shipping containers
R2	28,1	3,4	1,38	Traditional
R3	37,3	4,4	1,53	Traditional

The rooms in the traditional construction were empty, while the room in the container construction was furnished with the usual bedroom furniture (i.e., a large bed, two chairs and a small table). Consequently, the reverberation time of the latter room was significantly lower than that of the other two rooms measured, as can be seen in Table I.

The measurements were carried out according to the specifications of ISO 16283-3:2016 between the 1/3 octave bands of 50 and 5000 Hz. A microphone mounted on a fixed tripod at each of the microphone positions (in-space and corner) was used for the measurements. This tripod was moved manually by an operator to the different fixed positions in each of the rooms.

The following equipment was used for the measurements:

- a Brüel & Kjaer type 4224 directional sound source placed at an angle of 45º to the façade to be tested, as specified in the standard, and generating wideband noise between 50 and 5000 Hz. The directivity measurements and the calculation of the direct sound level radiated on a façade element met the specifications required by the standard on a surface of 4 x 3 m^2, which allowed the measurement to be carried out with only one source position.

- a Brüel & Kjaer type 2270 sound level analyzer.

- a Brüel & Kjaer type 4196 omnidirectional sound source for the measurement of the reverberation time according to the interrupted noise method described in ISO 3382-2:2008.

For the default measurement procedure, five microphone positions were used, evenly distributed over the available space in each of the rooms. These positions were chosen in accordance with the limiting distances between microphone positions and walls specified in the standard. In the case of the measurement following the specific low-frequency procedure (i.e., corner measurement), the sound pressure level was measured at four corners with the microphone fixed by means of a tripod, with two corners close to the floor and two corners close to the ceiling. The distance to the three surfaces forming the corners was set with the tripod between 0.3 and 0.4 m, as indicated in the standard. For each of the measurements in the receiving room (L_2), a measurement of the background noise (B_2) was carried out immediately afterwards. In this way, a high correlation between the measured background noise and the background noise existing during the measurement of each L_2 observation could be expected.

The outdoor noise level (L_1) was measured at a distance of 2 meters from the center of the façade.
The following calculation methods were used to calculate the $L_{2,LF}$ level for the 50, 63 and 80 Hz bands:

1) The default method specified by the standard when the volume of the enclosure is above 25 m^3: energetic average of the sound pressure level values measured at the five microphone positions evenly distributed over the enclosure surface.

2) The low-frequency calculation procedure specified in the standard according to expression (1), where $L_{2,corner}$ is the maximum of the sound pressure levels measured at all the corners for the 50, 63 and 80 Hz bands:

$$L_{2,LF} = 10lg\left[\frac{10^{0.1L_{2,corner}}+(2\cdot 10^{0.1L_2})}{3}\right] \quad (1)$$

3) According to expression (1) but with $L_{2,corner}$ being the energetic average of the sound pressure levels measured at the four corners for the 50, 63 and 80 Hz bands.

3 Results and discussion

It was found that at low frequencies (50, 63 and 80 Hz bands), for the conducted measurements, it was not always possible to comply with the L_2 being 10 dB above B_2, both for the default measurement method and for the low-frequency measurement procedure.

As an example, Table II shows the values of L_2 and B_2 for one of the three rooms and the 50, 63 and 80 Hz bands following both the default and the specific low-frequency procedure. For the low-frequency procedure, as discussed above, two calculations were performed. On the one hand, the calculation described in the standard, selecting the maximum level of those measured in the corners as $L_{2,corner}$. In that situation, $B_{2,corner}$ was taken as the value measured at the corner where the maximum L_2 was measured. On the other hand, an $L_{2,corner}$ was also derived by taking the average of the L_2 measured in all corners. In that case $B_{2,corner}$ was also computed as the energetic average of the levels measured at the four corners.

As can be seen in Table II, for the example room, following the default method, the difference between L2 and B2 was less than 10 dB for some of the low frequency bands which, therefore, required background noise correction. However, this difference significantly increases as the specific low-frequency procedure is applied, both for the calculation described in the standard as well as for the average calculation. In particular, all low-frequency bands show differences above 10 dB for the calculation based on the maximum, the same happening for the average calculation except for the 50 Hz band.

Table II. L_2 and B_2 values for the low-frequency bands and each calculation method: the default calculation for volumes higher than 25 m^3, the low-frequency calculation as described in the standard (i.e., taking the maximum) and the average low-frequency calculation (i.e., taking the average instead of the maximum).

Frequency (Hz)	L_2 default (dB)	B_2 default (dB)	$L_{2,\text{corner}}$ max (dB)	$B_{2,\text{corner}}$ max (dB)	$L_{2,\text{corner}}$ avg. (dB)	$B_{2,\text{corner}}$ avg. (dB)
50	41.6	37.4	48.3	37.6	44.2	38.3
63	45.5	36.6	55.0	41.0	52.8	40.1
80	40.1	24.9	49.2	31.5	47.7	32.5

Figures 1, 2 and 3 show, for each of the rooms, the value of $D_{ls,2m,nT}$ in third octave bands, additionally presenting the sound insulation resulting from each of the three methods described for the calculation of $L_{2,LF}$ in low frequencies. In all three rooms, as can be seen in Figures 1-3, the lowest insulation is found when $L_{2,LF}$ is calculated using the low-frequency procedure specified in the ISO 16283-3:2016. The sound insulation value decreases between 3 and 12 dB in the 50, 63 and 80 Hz bands when considering the specific low frequency procedure in all rooms, which had volumes larger than 25 m3, compared to the results obtained using the default procedure. This result, moreover, does not seem to be dependent on the type of construction (i.e., traditional or with shipping containers), nor on whether the receiving room is furnished or empty during the measurement. In particular, as it can be seen in Figure 1, the container-built room showed lower low-frequency insulation than traditionally built rooms, probably due to its lighter weight. In any case, for both types of construction the sound insulation decreased significantly when considering the specific low-frequency procedure.

Differences in the $D_{ls,2m,nT}$ value were also found, between 1 and 4 dB in this case, depending on whether for the low-frequency procedure the calculation of the L2,corner was based on the maximum or the average value of those measured in the four corners. Besides the sound insulation curve of each room, the values measured in each of the four corners for the 50, 63 and 80 Hz bands have been included in Figures 1-3 to show the variability of L_2 at the corners.

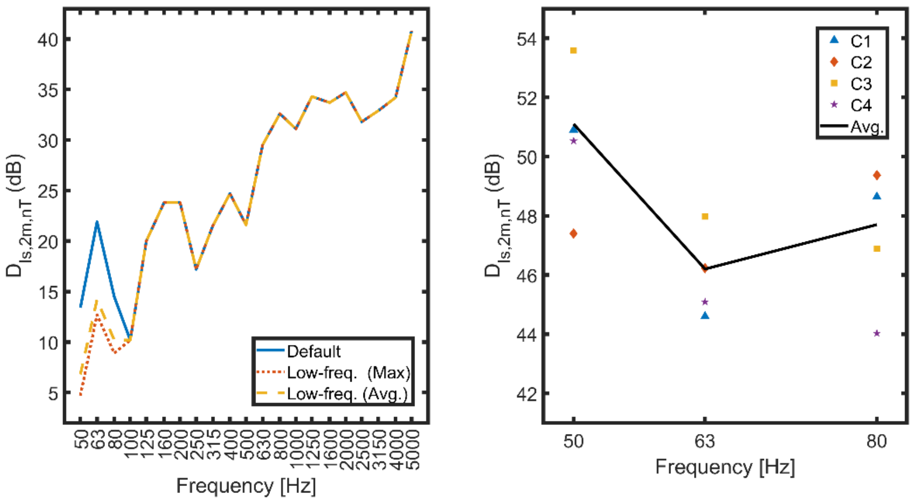

Figure 1: Room R1. Left - Sound insulation (i.e., $D_{ls,2m,nT}$) derived following the three calculations: default method, standardized low-freq. procedure, and average low-freq. procedure. Right – L_2 measured at each of the four corners as well as the average value for 50, 63 and 80 Hz bands.

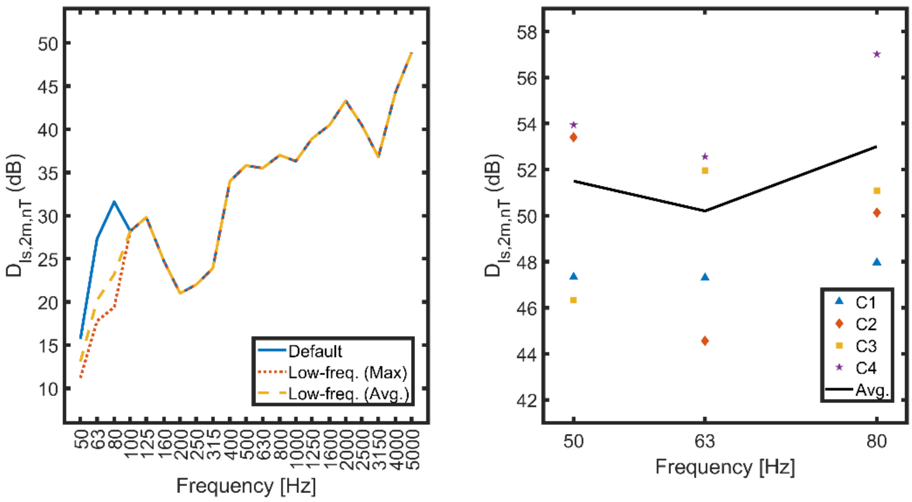

Figure 2: Room R2. Left - Sound insulation (i.e., $D_{ls,2m,nT}$) derived following the three calculations: default method, standardized low-freq. procedure, and average low-freq. procedure. Right – L_2 measured at each of the four corners as well as the average value for 50, 63 and 80 Hz bands.

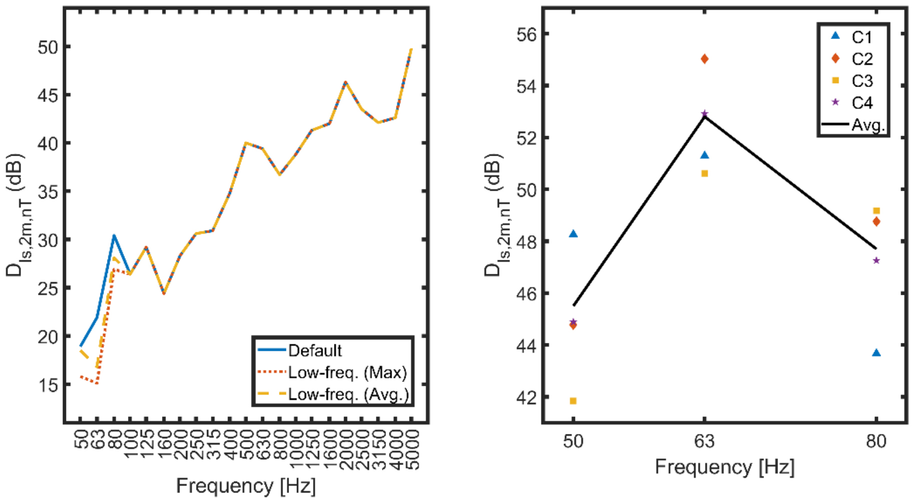

Figure 3: Room R3. Left - Sound insulation (i.e., $D_{ls,2m,nT}$) derived following the three calculations: default method, standardized low-freq. procedure, and average low-freq. procedure. Right – L_2 measured at each of the four corners as well as the average value for 50, 63 and 80 Hz bands.

It seems reasonable to think that the measurement of sound insulation in the 50, 63 and 80 Hz bands would be more accurate if the specific low frequency procedure is taken into account, even in enclosures with volumes above 25 m3, by explicitly taking into account the lack of diffusivity of the sound field at low frequencies. Furthermore, one would expect the results obtained with the default procedure and the specific low-frequency procedure to be equivalent, although more accurate in the case of the low-frequency procedure. However, for the measurements carried out during this research, the sound insulation values obtained using the default and low-frequency procedures differ significantly, with a considerable reduction in low-frequency sound insulation if the specific low-frequency procedure is employed, as shown in the left-hand boxes of Figures 1-3. Additionally, it seems necessary to consider which approach to the low frequency procedure is better, the one that takes the maximum value of those measured at the corners (i.e., the standardized method) or the one that takes the average value. Although the difference between the two is usually small, it may in some cases rather high, being as high as 4 dB in some of the obtained results. It therefore seems relevant to assess which of the two approaches most closely represents the actual sound insulation of the façade.

Additionally, an analysis was conducted to determine the effect that the different employed calculation procedures have on the single-number quantity $D_{2m,nT,Atr}$ of façade sound insulation. This single-number quantity was chosen because in Spain, the basic document "DB HR Noise Protection" [6] of the Spanish Technical Code (CTE) specifies that the A-weighted standardized level difference in façades and roofs for exterior car-dominant noise, $D_{2m,nT,Atr}$ (dBA) is the single-number to be used for the description of the sound insulation of the materials protecting an indoor environment from outdoor noise. In addition, this parameter is commonly adopted in the regulations of other European countries together with $D_{2m,nT,w}$ to express the airborne sound insulation of façades [7], with $D_{nT,Atr}$ also being the single value described in the recent ISO/TS 19488:2021 for the acoustic classification of façades [8]. The frequency range currently considered for the calculation of this single-number quantity is 100 to 5000 Hz, while in this analysis the range is extended in the lower frequency range to address the effect of low frequencies. Also, while this quantity should normally be presented rounded, it is presented here to one decimal place to make it easier to see the differences.

In view of the results obtained for the spectral parameter $D_{ls,2m,nT}$, it seemed interesting to analyze the differences that this entails in the single-number quantity $D_{2m,nT,Atr}$ if its calculation is extended down to 50 Hz, when taking into account the different calculation procedures of $L_{2,LF}$ for the 50, 63 and 80 Hz bands. Table III shows the value of this single number for the three calculation procedures of the magnitude $D_{ls,2m,nT}$ at low frequencies. It can be seen that the value of $D_{2m,nT,Atr}$ varies between 1 and 2 dB depending on the calculation procedure adopted, its value being always the lowest for the standardized low-frequency procedure, followed by the average low-frequency procedure and finally by the default procedure.

Tabla III. Value of $D_{2m,nT,Atr}$ between 50 and 5000 Hz for the three procedures for the calculation of low-frequency $D_{ls,2m,nT}$.

Room	**$D_{ls, 2m, nT, Atr}$**		
	L_2 default	$L_{2,corner}$ max	$L_{2,corner}$ avg.
R1	24.4	22.6	23.2
R2	30.4	29.1	29.8
R3	34.3	32.6	33.4

4 Conclusions

The implications have been shown of using the specific low-frequency procedure described in ISO 16283-3:2016 [3] for the measurement of airborne sound insulation of façades in rooms with volumes greater than 25 m^3.

The difference in the results depending on whether the default or the low-frequency procedure has been shown. In particular, it has been found that the low-frequency procedure leads to lower $D_{ls,2m,nT}$ values that using the default procedure for the 50, 63 and 80 Hz bands, this differences ranging from 3 to 12 dB. Regarding the single-number quantity $D_{2m,nT,Atr}$ (extended to the 50 to 5000 Hz range) differences between 1 and 2 dB could be found depending on whether the default or the specific low-frequency procedure was employed for the calculation of the low-frequency $D_{ls,2m,nT}$. However, further tests are necessary to establish whether these differences may be different depending on different conditions (e.g., the type of construction, the type of insulating material, etc.).

In any case, these results show that it is advisable to review whether it is appropriate to measure the sound insulation of façades following the specific low-frequency procedure for rooms with volumes greater than 25 m^3, given that its use could have an impact on the accuracy of the low-frequency assessments. Furthermore, the correct description of the sound insulation of façades at low frequencies is also fundamental for the subjective evaluation of the annoyance and loudness perceived by inhabitants at low frequencies, an aspect that has recently been the focus of listening tests and surveys related to sound insulation.

Although the results of this publication show that there are some differences between procedures, further measurements are needed to confirm these results, as well as to verify whether the conclusions drawn with respect to façade sound insulation can be extended to other kinds of sound insulation measurements, such as airborne sound insulation between dwellings or impact sound insulation. Finally, to confirm whether the conclusions hold or vary significantly if the volume of the receiving room is increased noticeably.

Depending on the type of sound insulation and incident noise, the incorporation of the low-frequency bands for the determination of the single-number quantities expressing the sound insulation can improve the relationship with people's subjective impression. However, to be clear about this dependency, and to be able to carry out conclusive subjective tests to determine which low frequency bands should be considered to express the sound insulation of facades perceptually, it is necessary to be clear about the best measurement procedure for the sound insulation below 100 Hz both for rooms of volume below and above 25 m^3. Previous research based on listening tests has already indicated the need for an extended frequency range, even down to the 20 Hz, for assessing impact sound insulation [9].

Finally, knowing the sound insulation of the façade and whether the measurement procedure is appropriate is crucial in the design of façades of buildings. For example, there is nowadays a trend in building construction towards lightweight construction systems, which offer the possibility of prefabrication, such as container-based housing, which are classified as more cost-effective and sustainable than concrete and traditional construction. These emerging building systems, however, generally perform worse at low frequencies than traditional construction due to their lower mass and the resonances they exhibit in the case of multi-sheet elements. It is therefore very important to establish whether there is a need to include the low frequency range to achieve a high perception of acoustic comfort when aiming at increasing the protection of building occupants against external noise. Consequently, the study of the need for these low frequency bands and their correct assessment should be a focus of working groups dealing with the measurement and the requirements of sound insulation in building regulations and standards.

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