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ON THE INFLUENCE OF REFERENCE REVERBERATION TIME ON FAÇADE SOUND INSULATION MEASUREMENTS

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ABSTRACT

The facade sound insulation measurements method is standardized in ISO 16283-3, which is being revised.
The standard includes two measurement methods: the element method and the global method. For the global sound insulation of a façade, the standardized level difference, $D_{2m,nT}$ is used. This level difference is standardized to a reference value of the reverberation time, T_0, in the receiving room. For dwellings, T_0 is equal to 0.5s.
This paper aims to evaluate the influence of the reverberation time (T) correction of the receiving room, with respect to the reference value T_0, at the variation of the T value, itself.
The results of measurements on site in receiving rooms with different volume and different reverberation times are compared.

Keywords: *façade sound insulation; reverberation time; ISO 16283-3.*

1. INTRODUCTION

The façade sound insulation measurement is standardized in ISO 16283-3. This standard specifies procedures to determine the airborne sound insulation of façade elements (element methods) and whole façades (global methods) using sound pressure measurements. Even if standard ISO 16283-3 suggests using the real traffic for whole façade measurements because it is the most accurate method to estimate the outdoor/indoor difference under actual traffic conditions, the global method with loudspeaker was used in this study. As underlined in a previous study [1], the traffic noise may not be constant during a day or a week, so its repeatability is unknown and cannot be used for this study.
The global method also includes measuring the reverberation time in the receiving room. In previous research [2, 3], on a dataset of 334 façade measurements, it was shown that the furnish typology of the receiving rooms (furnished or unfurnished) influences the measured data and, in particular, the Reverberation Time (T).
Façade sound insulation measurements are usually performed before a building unit is sold, and therefore with unfurnished rooms unless, in case of complaints, when the rooms are furnished. Consequently, it is essential to understand if and how much the furnish typology of receiving rooms influences the façade sound insulation.
The aim of this study is to analyze the influence of the reverberation time on the façade sound insulation and, therefore, the influence of the furnish typology of the receiving room.

2. MATERIALS AND METHODS

In order to analyze the reverberation time influence on the façade sound insulation, two rooms of different sizes were chosen.
The first is a room of 41 m^3 volume (Figure 1), used in a previous Round Robin Test on façade sound insulation [3]. The façade is a prefabricated concrete facade with a PVC frame and double glazing 4/12/4 window. The facade is situated on the first floor. The receiving room is an empty rectangular room with the following dimensions: 2.67 m in height, 3.25 m in width and 4.72 m in depth. The facade surface is 8.7 m^2, and the area of the window is 2.1 m^2.
The second is a room of 135 m^3 volume (Figure 2). The façade is a prefabricated concrete façade with 5 cm of

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internal thermal insulation, an aluminum frame with double glazing 4/12/4 windows, and a safety exit. The façade is located on the ground floor. The receiving room is a university classroom with furniture and a sound-absorption ceiling. The dimensions are from 2.5 to 2.85 m in height, 5.80 m in width and 8.30 m in depth. The facade surface is 16.5 m^2, and the total area of windows and safety exit is 8.2 m^2.

The standardized level difference of facade $D_{ls,2m,nT}$, is the level difference in decibels, corresponding to a reference value of the reverberation time in the receiving room:

$$D_{ls,2m,nT} = D_{2m} + 10\ lg(T/T_0) \tag{1}$$

Where:

ls simply indicates that a loudspeaker was used instead of real traffic noise (notation *tr*);

T is the reverberation time in the receiving room;

T_0 is the reference reverberation time for dwellings T_0=0.5s;

D_{2m} is the level difference, i.e., the difference, in decibels, between the outdoor sound pressure level 2 m in front of the facade, $L_{1,2m}$, and the space and time average sound pressure level, L_2, in the receiving room:

$$D_{2m} = L_{1;2m} - L_2 \tag{2}$$

The measurements were repeated to analyze the influence of the reverberation time on the façade sound insulation, adding sound absorption inside the rooms. The additional sound absorption was reached with polyester fiber (PET) panels distributed along the useful surface of the rooms (**Figure 1** and **Figure 2**).

Figure 1. Internal view of the 41m^3 room, with polyester fiber (PET) acoustic panels

In both cases, the maximum surface used of the panels was about 28% of the internal surface of the room, namely 100% of the surface of the material used. Then the following measurement was repeated with the 75%, 50%, 25% and 0% of the surface of the panels, in both rooms. An additional measurement was performed for the smaller room by simulating a sofa/futon. In the case of the university classroom, an additional measurement with 12.5% of the surface of the panels was performed.

Figure 2. Internal view of the 135m^3 room with polyester fiber (PET) acoustic panels

3. RESULTS AND DISCUSSION

In the following figures, the results of the measurements are shown. As expected, the variation of reverberation time measurements depends on the percentage of panels used (**Figure 3** and **Figure 6**).

It is worth noticing that the major variation occurs when the first set of panels is introduced in the rooms, while the variations are smaller with the increase in the number of panels.

The results of standardized level difference of facade $D_{ls,2m,nT}$ for both rooms are shown in the next figures.

Contrary to the results of reverberation time measured, the results of the measurements of standardized level difference of facade $D_{ls,2m,nT}$ differ in the two rooms. In the smaller room (**Figure 4**), the variation of reverberation time seems to not influence $D_{ls,2m,nT}$. In comparison, there is a noticeable difference in the bigger room (Figure 7) when the first amount of panels was introduced. In this case, the quantity introduced is 12.5% of the panels, which is 4% of the room's internal surface. It means that, with only about 6m^2 of panels surface, the standardized level difference of façade changes.

To analyze this behavior in deeper detail, the internal levels were compared for both rooms.

As expected, the internal levels are higher for the empty configuration in both rooms. Nevertheless, this behavior has a reflection only in the case of bigger room.

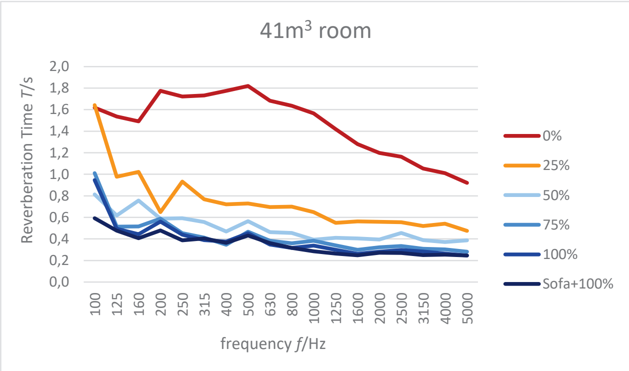

Figure 3. Reverberation Time in 41m^3 room at the variation of the surface of the panels.

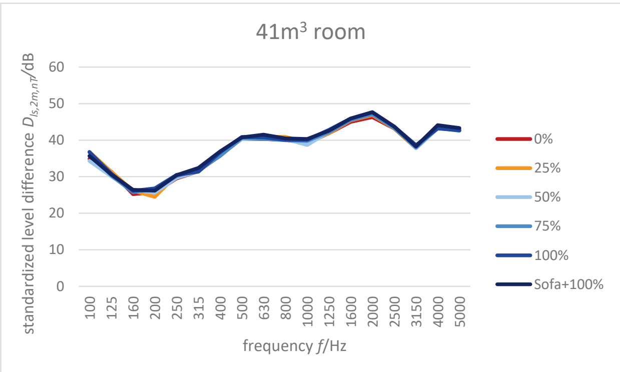

Figure 4. Standardized level difference of facade $D_{ls,2m,nT}$ in 41m^3 room at the variation of the surface of the panels.

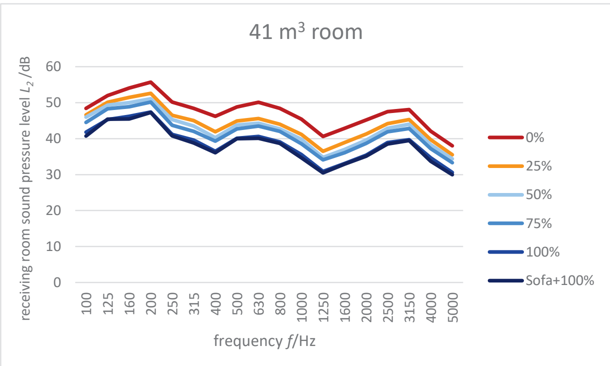

Figure 5. Sound pressure level, L_2, in the receiving 41m^3 room at the variation of the surface of the panels.

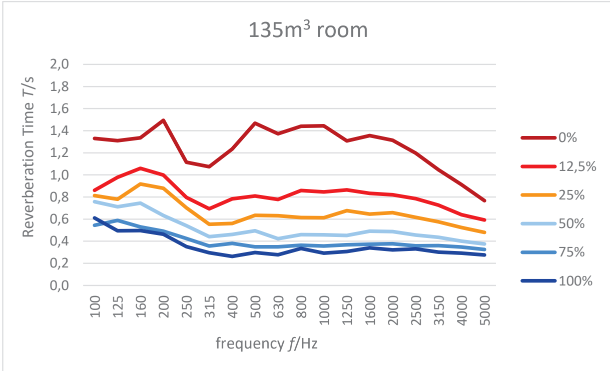

Figure 6. Reverberation Time in 135m^3 room at the variation of the surface of the panels

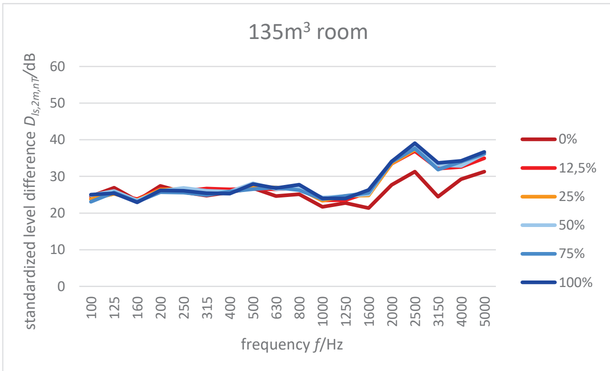

Figure 7. Standardized level difference of facade $D_{ls,2m,nT}$ in 135m^3 room at the variation of the surface of the panels.

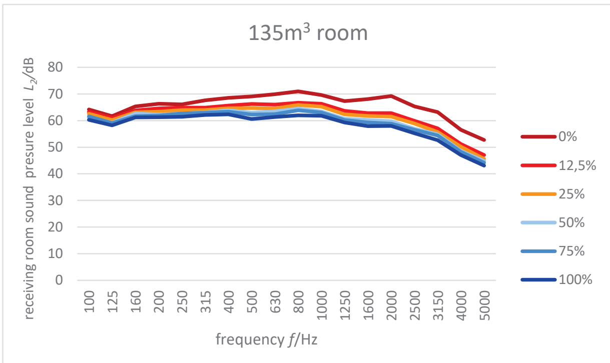

Figure 8. Sound pressure level, L_2, in the receiving 135m^3 room at the variation of the surface of the panels.

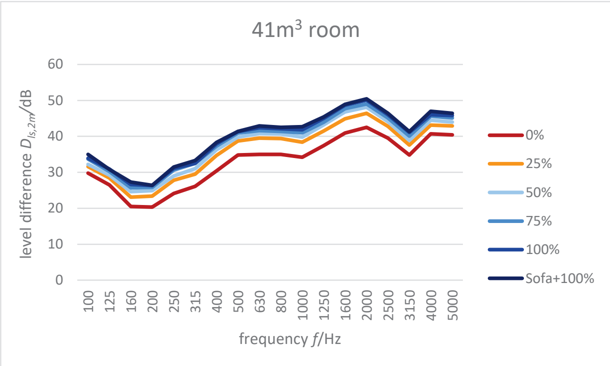

Figure 9. Level difference $D_{ls,2m}$ for 135m^3 room at the variation of the surface of the panels.

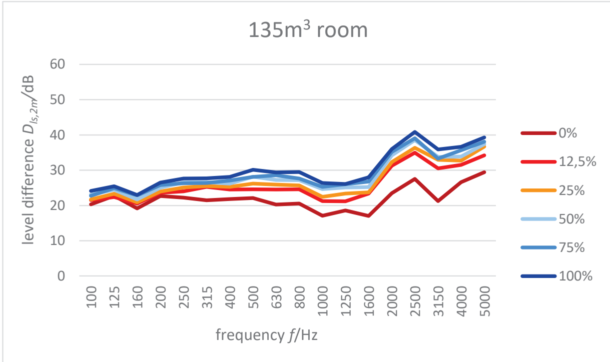

Figure 11. Level difference $D_{ls,2m}$ for 135m^3 room at the variation of the surface of the panels.

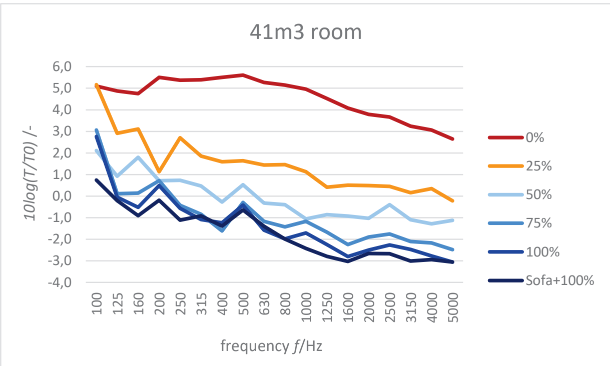

Figure 10. Correction term *10lg T/T₀* for 41m^3 room at the variation of the surface of the panels.

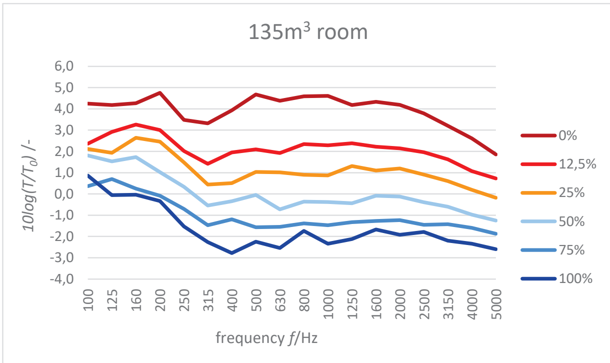

Figure 12. Correction term $10lg\ T/T_0$ for 135m^3 room at the variation of the surface of the panels.

Even if in the smallest room the variation in $D_{ls,2m,nT}$ is not noticeable, a higher internal sound pressure level (**Figure 5**) could be a discomfort for the inhabitants, and this is not reflected in façade sound insulation $D_{ls,2m,nT}$.
It is, therefore, necessary to understand how the correction term $10lg\ T/T_0$ affects the result of the measurement.
This was done by comparing, on the one hand, the level difference $D_{ls,2m}$ (Equation 2) and, on the other hand, the correction term at the variation of the surface of the panels (**Figure 10** and **Figure 12**).
Therefore, the correction term plays a crucial role in the quantity evaluated, namely $D_{ls,2m,nT}$.
Table 1 also indicates the average correction term, averaged from 100 to 5000 Hz.
As expected, $D_{ls,2m}$ shows more differences in the variation of the surface of the panels than the standardized level difference.

Therefore, the correction term plays a crucial role in the quantity evaluated, namely $D_{ls,2m,nT}$.

Table 1. Average correction term $10lg\ T/T_0$ averaged from 100 to 5000 Hz

	Average $10lg\ T/T_0$ / dB	
Surface of the panels	Smaller room	Bigger room
0%	4.6	3.9
12.5%	-	2.1
25%	1.5	1.1
50%	-0.1	0.0
75%	-1.0	-1.0
100%	-1.3	-1.6
Sofa+100%	-1.7	-

Concerning the single number quantity, $D_{ls,2m,nT,w}$, in the smaller room, the difference between the empty room and

the room with extra absorption is up to 0.8dB, lower than the in situ standard deviation as per ISO 12999-1 [5]. It is worth noticing that $D_{ls,2m,nT,w}$ measured in the smaller room has a value very near to the average value equal to 40.0 dB found in the previous RRT [4].
Moreover, the use of 0.5s for the reference reverberation time in the smaller room led to a correct evaluation of the sound field. Therefore, the final façade sound insulation results are very similar in both furnished and unfurnished situations.
On the contrary, this is not the case for the bigger room, where there is a difference of more than 3dB when some extra absorption is introduced (Table 2). This difference is higher than the measurement uncertainty, even if the 95% confidence level is considered [6].

Table 2. Weighted standardized level difference of façade $D_{ls,2m.nT.w}$

	$D_{ls,2m,nT,w}$ /dB	
Surface of the panels	Smaller room	Bigger room
0%	39.9	25.4
12.5%	-	28.2
25%	40.1	28.3
50%	40,1	28.6
75%	40.2	28.3
100%	40.6	28.7
Sofa + 100%	40.7	-

On the one hand, the average correction term (**Table 1**) has similar values for both the smaller and the bigger room at the variation of the surface of the panels. On the other hand, this should have led to a similar correction in $D_{ls,2m,nT}$ values. However, this is not the case.
To analyze this behavior more deeply, the Schroeder frequency was calculated as the reverberation time varies in both rooms.
The sound field in both rooms is not perfectly diffuse, in general, and in particular under the Schroeder frequency, f_s [7]:

$$f_s = 2000\sqrt{\frac{T}{V}} \tag{3}$$

The average reverberation time can be used to calculate the Schroeder frequency from measured reverberation time values, which are approximately constant over the frequency range used in building acoustics. Otherwise, an initial estimate for the Schroeder frequency can be found from the arithmetic average of the reverberation time over a large part of the frequency range [8].
As shown in previous research, in the smaller room when empty, the average reverberation time is 1.64 s, calculated in the frequency range 50-5000 Hz from the average of the values taken in 5 repetitions of the measurements by 10 laboratories (see Fig. 3 of [4]). Thus, the Schroeder frequency is 400 Hz. A different trend was also shown under the Schroeder frequency of 400 Hz. At the same time, above it, where the sound field is diffuse, the average and maximum sound pressure levels measured in the corners are comparable [9].
In Table 3, the 1/3 octave band, in which the calculated Schroeder frequency (in the frequency 100-5000 Hz) falls, are indicated as the reverberation time varies.

Table 3. One-Third Octave Band in which the Schroeder frequency falls.

	1/3 octave band in which f_s falls / Hz	
Surface of the panels	Smaller room	Bigger room
0%	400	200
12.5%	-	160
25%	250	125
50%	200	125
75%	200	100
100%	200	100
Sofa + 100%	200	-

Therefore, it is possible to conclude that in a small room, the diffusivity of the sound field does not affect the facade standardized level difference. While, in a bigger room, $D_{ls,2m,nT}$ is affected by the sound field diffusivity and the modal overlap factor due to the normal modes.
To evaluate the sound field distribution within the largest room, the procedure for calculating the $D_{2,S}$ parameter was used [10]. The spatial decay rate of speech $D_{2,S}$ is the rate of spatial decay of A-weighted sound pressure level (SPL) of speech per distance doubling in decibels.
The spatial decay of the sound pressure level around the Schroeder frequency in the various setups with different percentages of sound-absorbing material will be analyzed. (**Figure 13** and **Figure 14**)

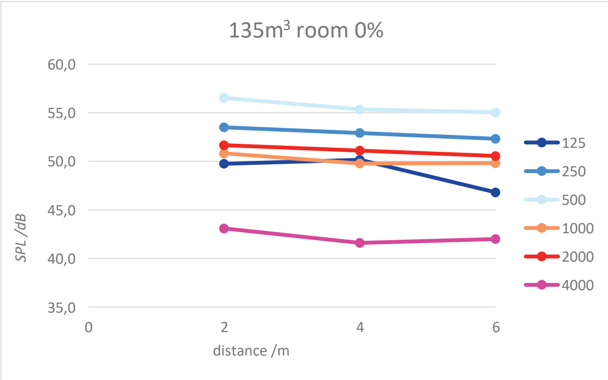

Figure 13. The spatial decay of the sound pressure level without the sound-absorbing material.

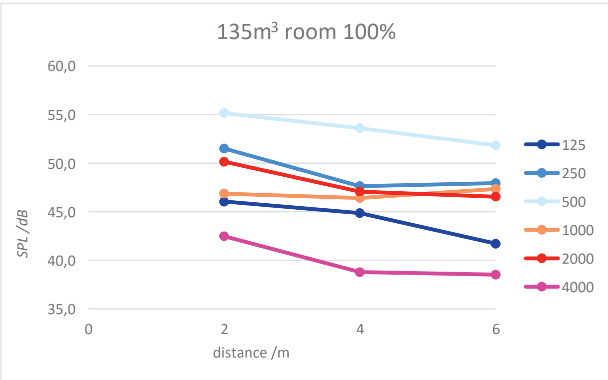

Figure 14. The spatial decay of the sound pressure level with 100% sound-absorbing material.

The sound-absorbing material modifies the spatial distribution of sound pressure level [11]. However, this is evident with high percentages of material.
A final consideration can be made based on the type of sound-absorbing material used. For instance, Polyester fiber has both active and reactive behavior. While the active part modifies the reverberation time, the reactive part modifies the modal overlap factor at low frequencies, effectively changing the sound field within the room, and it is well-recognizable with innovative materials [12]. When additional porous material is placed into the room, some modes with high peak factor – i.e. axial modes – are dampened by the added viscous losses.

4. CONCLUSIONS

The influence of reverberation time on the façade sound insulation was measured and analyzed in two different rooms, one small (41m^3) and one bigger (135m^3).
It was found that in the small room, the influence of the reverberation time on the façade sound insulation is negligible, lower than the measurement uncertainty. In fact, the use of 0.5s for the reference reverberation time in the smaller room led to a correct evaluation of the sound field; therefore, the final façade sound insulation results are very similar in both furnished and unfurnished situations.
On the contrary, in the bigger room, with only about 6m^2 of panels surface, the standardized level difference of façade changes.
By analyzing the Schroeder frequency, we concluded that in a small room, the diffusivity of the sound field does not affect the facade standardized level difference. While in a bigger room, $D_{ls,2m,nT}$ is affected by the sound field diffusivity.
The next steps will be to perform the same measurement campaign in a room around 250 m^3, the volume limit included in the standard and in a very big room, bigger than, let's say 300 m^3, like an open plan office.

5. ACKNOWLEDGMENTS

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