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PREDICTIONS VS MEASUREMENTS: NEW ISO 12354 APPLIED TO SPANISH HOUSING

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ABSTRACT

Standardized prediction models for airborne and impact sound insulation described in the standard ISO 12354, parts 1 and 2, are the most commonly used prediction models among acousticians to comply with Spanish regulations. The new version of the standard published in July 2017 includes new calculation procedures with respect to the previous version.

This paper shows a study with the comparison of the predictions made with these prediction models applied to the Spanish dwelling houses and the real acoustic insulation measurements carried out in several buildings which comply with the current regulations in Spain, Basic Document DB HR Protection against noise of the Building Code.

This paper compares predictions and acoustic insulation measurements of airborne and impact noise on both, walls and floors.

1. INTRODUCTION

This paper shows a comparative study carried out in several typical buildings of current Spanish constructions, built under the current regulations, Basic Document, DB HR, Protection against Noise [1], of the Spanish Building Code, CTE [2]. The study compares predictions made with the calculation methods described in the standard ISO 12354-1 [3] and 2 [4], with field measurements.

DB HR requirements could be justified by several options, one of which is the calculation in the project phase of the noise transmission between rooms and the simulation of the final insulation. Although there are several calculation models, the most widespread is the one included in the standard ISO 12354.

In July 2017, a new version of standard ISO 12354 was published, which includes new features regarding the calculation compared to the previous version. This standard contains the calculation model to estimate the *in situ* sound insulation from the performance of the construction elements obtained in the laboratory. This calculation model is the most used to justify the acoustic regulation in Spain, DB HR CTE.

The field measurements have been carried out in accordance with the standard ISO 16283, parts 1 [5] and 2 [6] and the comparisons between simulations and *in situ* tests have been made based on the standardized level difference, D_{nT} , and standardized impact sound pressure level, L'_{nT} .

2. FIELD MEASUREMENT BUILDINGS

The measurements were made in five dwelling buildings located in Madrid Autonomous Community (Spain). These dwellings were built between 2015 and 2018 under the current Spanish regulations, Basic Document, DB HR, Protection against Noise.

In all the buildings of this study, the rooms where the airborne and impact sound insulation tests were carried out were chosen as the most unfavorable for each case, in all cases being two small bedrooms belonging to adjacent dwellings both horizontal as vertically.

The following table shows the construction elements associated with each test, as well as the volume of the receiving room and the surface of the separating element of each of the rooms tested.

	Const. element	Test	Volume (m ³)	Area (m ²)
ESV_1	Wall	Airbone	31,25	10,45
ESV_2	Wall	Airbone	26,68	7,32
ESH_A_2	Floor	Airbone	26,68	10,1
ESH_I_2	Floor	Impact	26,68	10,1
ESV_3	Wall	Airbone	22,80	7,7
ESV_4	Wall	Airbone	25,70	9,85
ESH_A_4	Floor	Airbone	25,70	10,19
ESH_I_4	Floor	Impact	25,70	10,19
ESV_5	Wall	Airbone	22,66	7,10
ESH_A_5	Floor	Airbone	22,66	8,41
ESH_I_5	Floor	Impact	22,66	8,41

Table 1. Field measurement characteristics.

Construction elements of the measurements rooms are the usual ones in current Spanish new build housing, with small differences between different buildings.

Generally, 350 mm wide beam and block floors with ceramic or light aggregate blocks, as well as 350 mm grid floors with light aggregate blocks as the separating floors found in dwellings. Typical floating floors consist of at least 50 mm cement screed and a resilient layer like polyethylene, mineral wool or elastified expanded polystyrene.

Light steel frame walls composed of gypsum board and mineral wool and single leaf masonry walls with two linings consisting on gypsum boards fixed to independent

steel frames are the most used as separating walls in current dwelling buildings.

In addition, facades are composed by an external wall, a cavity with thermal insulation panels and an internal lining such as one or two layers of gypsum board.

3. SOUND INSULATION MEASUREMENTS

The sound insulation measurements were carried out by the Building Acoustics Laboratory of the Eduardo Torroja Institute for Construction Sciences (IETcc). This study is part of the pre-normative research carried out by the Building Quality Unit at IETcc which assists the Ministry of Infrastructure of Spain in maintaining the Spanish Building Code.

3.1 Airborne sound insulation

The procedure to determine the airborne sound insulation between two rooms was done according to ISO 16283-1:2014. This procedure is intended for room volumes in the range from 10 m³ to 250 m³ in the frequency range from 50 Hz to 5 000 Hz in one-third octave bands.

The measured airborne sound insulation is frequency-dependent and has been converted into a single number quantity to characterize the acoustic performance using the rating procedures in ISO 717-1 [7].

The parameter used to determine the airborne sound insulation was standardized level difference, D_{nT} , calculated using formula:

$$D_{nT} = L_1 - L_2 + 10 \cdot \lg \frac{T}{T_0} \quad (\text{dB}) \quad (1)$$

Where

- L_1 : is the energy-average sound pressure level in the source room (dB)
- L_2 : is the energy-average sound pressure level in the receiving room (dB)
- T : is the reverberation time in the receiving room (s)
- T_0 : is the reference reverberation time; for dwellings, $T_0 = 0,5\text{s}$.

Table 2 shows the single number quantities results obtained in the airborne sound insulation measurements in the frequency range from 100 Hz to 5000 Hz.

In the same way, the D_{nTA} ($D_{nTA} \approx D_{nT,w} + C$) is shown because is the insulation quantity required in Basic Document, DB HR, Protection against Noise of the Spanish Building Code, CTE.

	$D_{nT,w} (C; C_{tr})$ 100-3150	$D_{nT,w} (C; C_{tr})$ 100-5000	$D_{nT,A}$
ESV_1	65 (-3; -9)	65 (-2; -9)	62,6
ESV_2	55 (-3; -9)	55 (-2; -9)	52,9
ESH_A_2	58 (-1; -6)	58 (-1; -6)	57,4
ESV_3	61 (-5; -12)	61 (-4; -12)	57,1
ESV_4	58 (-3; -8)	58 (-2; -8)	56,3
ESH_A_4	58 (-3; -9)	58 (-2; -9)	56,3
ESV_5	59 (-6; -14)	59 (-5; -14)	54,2
ESH_A_5	68 (-4; -10)	68 (-3; -10)	65,2

Table 2. Results of airborne sound insulation of the *in situ* measurements.

3.2 Impact sound insulation

The procedure to determine the impact sound insulation using sound pressure measurements was done according to ISO 16283-2:2018. This procedure is intended for room volumes in the range from 10 m³ to 250 m³ in the frequency range from 50 Hz to 5000 Hz in one-third octave bands.

A single number quantity can be calculated using the rating procedures in ISO 717-2 [8]. This single number quantity links the measured impact sound insulation using the tapping machine to subjective assessment of general impacts in dwellings

The parameter used to determine the impact sound insulation was standardized impact sound pressure level, L'_{nT} , calculated using formula:

$$L'_{nT} = L - 10 \lg \frac{T}{T_0} \quad (\text{dB}) \quad (2)$$

Where

- L : energy-average impact sound pressure level in the receiving room (dB)
- T : is the reverberation time in the receiving room (s)
- T_0 : is the reference reverberation time; for dwellings, $T_0 = 0,5\text{s}$.

Table 3 shows the global results obtained in the impact sound insulation measurements in the frequency range from 100 Hz to 2500 Hz.

	$L'_{nT,w} (C_1)$ 100-2500
ESH_I_2	51 (1)
ESH_I_4	51 (1)
ESH_I_5	47 (1)

Table 3. Results of impact sound insulation of the *in situ* measurements.

4. PREDICTIONS

Simulations have been made using the sound insulation calculation program SONarchitect [9]. This software computes all the sound insulation values in one-third octave bands in the entire building according to ISO 12354.

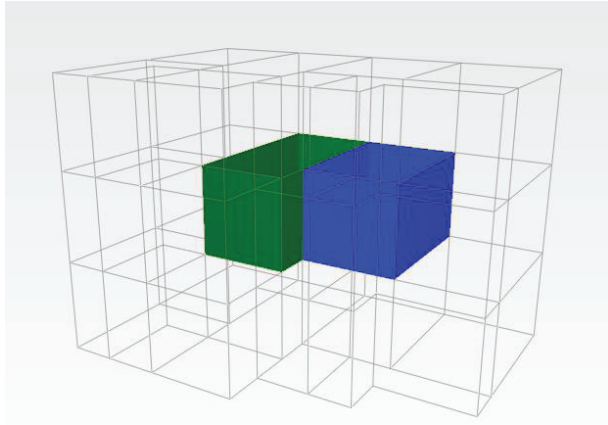


Figure 1. SONarchitect simulation picture.

The modeling of the dwellings buildings has been made following the real geometry of the tested rooms. Joints between different materials were taking in mind and the same construction building elements have been used for the simulations except for several approaches.

These approaches have been necessary because software databases do not contain all construction elements used in the Spanish construction. Besides, on many occasions, we do not have the laboratory test data of the construction element to simulate.

It is common to conduct these approximations when more precise data are not available. ISO 12354-1 indicates that acoustic insulation values obtained in laboratories are preferable than theoretical estimates, however, the greatest difficulty, when using this method, lies in having reliable values at all frequencies.

There are a lot of data from software databases and catalogs for vertical partitions, however, there are very few sound insulation test data for beam and block floors, which are the most frequent in Spanish buildings.

ISO 12354-1 indicates that when there is no information about construction elements, it is convenient to vary the input data in such a way that an estimate of the precision of the calculation can be obtained.

In this work, the calculations have been made with different slabs, some of them resulting from calculations, finally the one with which the best estimate of sound insulation was obtained has been chosen.

Table 4 and table 5 show global results obtained by simulation.

	$D_{nT,w}(C; C_{tr})$ 100-3150	$D_{nT,w}(C; C_{tr})$ 100-5000	$D_{nT,A}$ 100-5000
ESV_1	70 (-3; -10)	70 (-2; -10)	69
ESV_2	58 (-2; -6)	58 (-1; -6)	57
ESH_A_2	63 (-2; -7)	63 (-1; -7)	62
ESV_3	56 (-2; -6)	56 (-1; -6)	55
ESV_4	58 (-2; -6)	58 (-1; -6)	57
ESH_A_4	61 (-1; -5)	61 (-1; -5)	60
ESV_5	59 (-4; -10)	59 (-3; -10)	55
ESH_A_5	67 (-2; -8)	67 (-2; -8)	62

Table 4. Predicted results for airborne sound insulation.

	$L'_{nT,w}(C_I)$ 100-2500
ESH_I_2	51 (1)
ESH_I_4	51 (1)
ESH_I_5	49 (1)

Table 5. Predicted results for impact sound insulation.

5. COMPARISON BETWEEN MEASURED DATA AND CALCULATED DATA

Measurement data from *in situ* measurement were collected and compared to theoretical calculations.

Table 6 shows data from sound insulation measurements and simulations comparing the standardized level difference, D_{nT} , in the frequency range from 100 Hz to 5000 Hz.

In addition, table 7 shows data from impact sound insulations from measurements and predictions based on the standardized impact sound pressure level, L'_{nT} , in the frequency range from 100 Hz to 2500 Hz.

F (Hz)	D_{nT} 1/3 octava (dB)															
	ESV 1		ESV 2		ESH A 2		ESV 3		ESV 4		ESH A 4		ESV 5		ESH A 5	
	TEST	SIM	TEST	SIM	TEST	SIM	TEST	SIM	TEST	SIM	TEST	SIM	TEST	SIM	TEST	SIM
100	41,6	40,1	26,1	35,5	38,9	42,4	30	35,3	30,8	36,6	45,3	46,9	26	34,8	43,6	47,0
125	39,3	49,4	41,2	38,9	35,8	47,1	37	37,7	42,3	39,3	32,4	46,8	34,9	37,3	46,4	47,3
160	47,5	53,3	44,8	42,3	43,7	42,5	41,2	37,4	41,2	44,6	40,9	43,7	39,7	37,3	44,7	44,3
200	55,3	58,8	51,6	48,5	49,4	48,3	50,5	43,4	48,3	48,2	47,3	47,0	50,4	43,5	56,5	47,6
250	59,9	66,7	53,1	52,1	49,5	53,5	55,8	51,3	54,9	52,8	51,8	56,5	53,1	51,3	61,1	58,2
315	61,2	68,1	56	56,7	49,7	59,9	58,2	57,7	56,9	57,2	49,8	61,4	55,2	57,6	62	65,3
400	64,9	75,4	57,5	59,3	53,1	63,6	60,3	62,3	60,7	59,6	52,2	64,7	58,1	62,1	61,7	68,4
500	67,1	77,6	54,5	58,9	52,8	64,6	62,5	59,5	64,2	58,9	56,1	63,9	62,6	59,7	69,4	66,6
630	69,3	78,8	59,3	60,3	55,4	65,4	66,2	59,4	62,8	60,3	57,5	65,2	64,2	59,9	74,5	67,6
800	67,5	78,8	62,2	58,0	62,8	62,8	64,7	56,4	62,7	57,6	61,9	59,0	64,8	56,8	80,7	61,4
1000	70,7	78,4	63,7	55,8	68,6	59,8	66,2	52,3	60,2	55,6	66,2	58,7	65,1	52,7	84,5	59,9
1250	71,7	82,6	60,6	58,4	71,2	65,7	65	55,4	59,6	58,2	67,3	62,4	64,1	55,7	86,3	64,0
1600	71,3	83,0	56,5	61,8	67,7	71,0	67,9	64,4	62,1	61,7	68,9	70,0	64,2	64,1	87,4	77,8
2000	64,8	75,5	51,1	59,6	65,2	71,3	69,1	65,8	57,1	59,7	65,2	67,6	63	64,5	86	74,7
2500	62,3	69,4	53,4	56,1	67,5	67,7	70,3	61,0	56,5	56,7	64,3	62,1	61,4	59,4	82,3	68,3
3150	69,0	74,9	55,2	59,5	70,5	70,4	69,9	61,4	60,7	60,0	68,4	62,3	62,5	60,4	82,7	68,5
4000	75,3	74,8	58,2	60,0	71,1	71,0	70,8	60,4	62,4	60,3	73,3	61,4	63,9	59,6	79,9	66,2
5000	73,9	74,5	62,1	60,3	66	68,1	67,6	60,9	66,2	61,0	74,2	63,0	65,6	60,0	75,8	68,1

Table 6. Comparison of field measurements and predictions for airborne sound insulation.

F (Hz)	L_{nT} 1/3 octave (dB)					
	ESH I 2		ESH I 4		ESH I 5	
	TEST	SIM	TEST	SIM	TEST	SIM
100	55,3	54,9	53,9	56,9	54,1	58,8
125	63,6	57,5	62,8	57,6	58,4	58,6
160	57,6	62,2	60,4	62,7	59,1	61,2
200	56,3	55,5	57,2	60,1	53,2	55,0
250	57,3	58,8	54,2	55,9	48,1	47,4
315	57,3	52,1	54,7	48,7	44,4	39,4
400	52,4	47,3	52,9	48,5	45	37,5
500	47,7	49,4	45,1	46,5	36,3	33,7
630	45,3	46,6	41,2	44,2	31,9	30,4
800	42,2	46,7	38,4	42,2	25,2	26,0
1000	30,4	44,3	30,1	40,6	19	23,1
1250	26,1	39,6	27,7	36,6	16,1	18,6
1600	22,8	39,4	22,3	35,0	15,2	17,0
2000	21,6	35,6	22,2	32,0	13,8	15,4
2500	19,3	31,9	19,2	27,0	11,8	13,1
3150	13,5	23,5	13,8	15,6	8,7	1,1
4000	10,0	16,9	10,6	11,4	6,5	-3,6
5000	6,1	8,9	6,6	10,8	6,0	-4

Table 7. Comparison of field measurements and predictions for impact sound insulation.

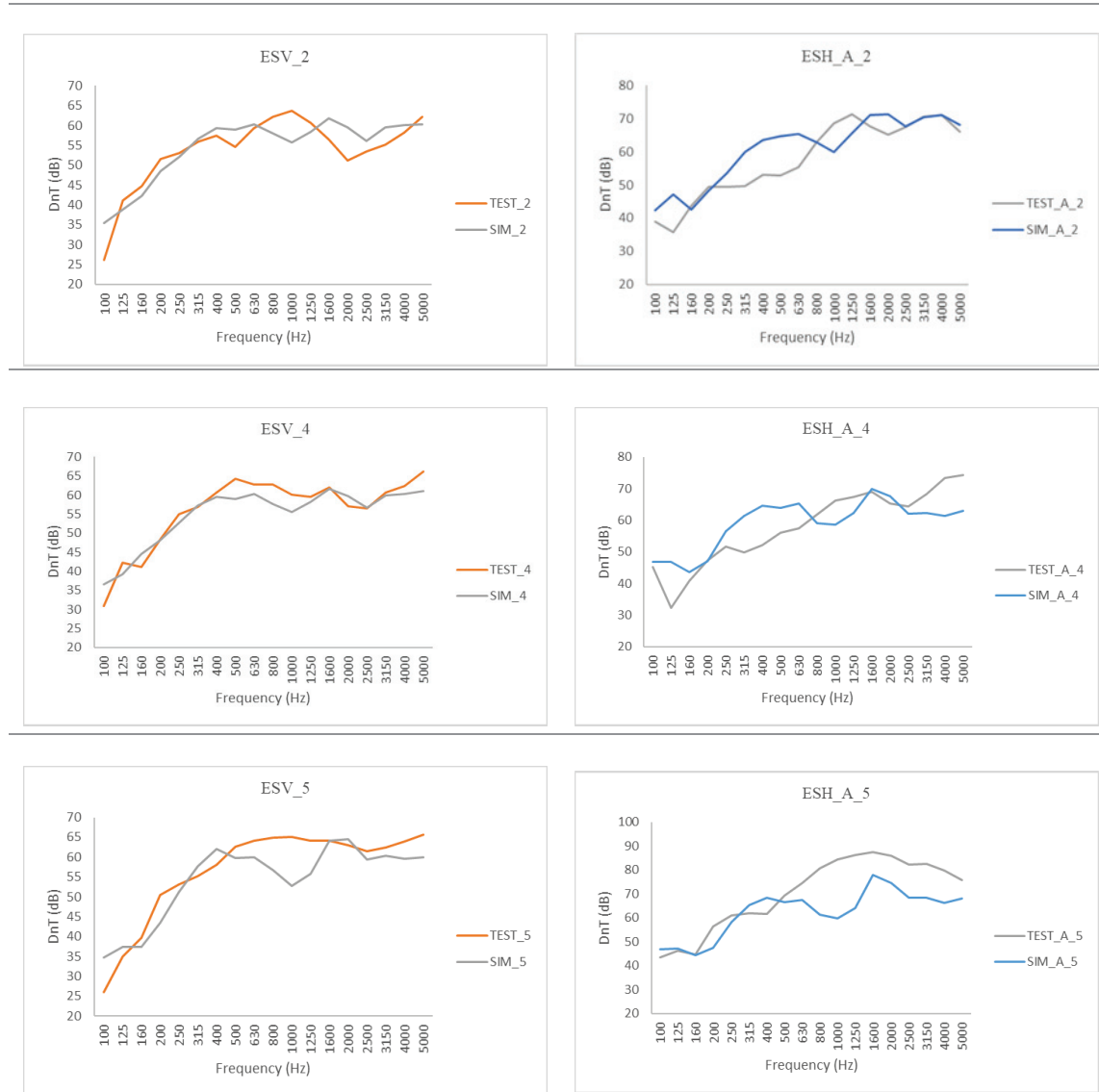


Figure 2. Comparison examples of airborne sound insulation spectra.



Figure 3. Comparison examples of impact sound insulation spectra.

Figure 2 and figure 3 show several examples of the comparison of airborne and impact sound insulation spectra.

As can be seen in the comparison (table 8 and figure 4) of the global results of airborne sound insulation between the tests carried out *in situ* and the simulations using software, different values of the standardized level difference, $D_{nT,w}$, are observed.

Taking into account the data of the separating walls, an increase of $D_{nT,w}$ between 0dB and 5 dB is observed in the theoretical calculations. Likewise, $D_{nT,A}$, also suffers a variation between the real test and the theoretical simulation between 1 dBA and 6 dBA.

In addition, according with the data of separating floors, an increase of $D_{nT,w}$ between 1dB and 5 dB is observed in the theoretical calculations.

	$D_{nT,w} (C; C_{tr})$ 100-3150	$D_{nT,w} (C; C_{tr})$ 100-5000	$D_{nT,A}$ 100-5000
ESV_1			
Test	65 (-3; -9)	65 (-2; -9)	62,6
ESV_1			
Simulation	70 (-3; -10)	70 (-2; -10)	68
ESV_2			
Test	55 (-3; -9)	55 (-2; -9)	52,9
ESV_2			
Simulation	58 (-2; -6)	58 (-1; -6)	57
ESH_A_2			
Test	58 (-1; -6)	58 (-1; -6)	57,4
ESH_A_2			
Simulation	63 (-2; -7)	63 (-1; -7)	62
ESV_3			
Test	61 (-5; -12)	61 (-4; -12)	57,1
ESV_3			
Simulation	56 (-2; -6)	56 (-1; -6)	55
ESV_4			
Test	58 (-3; -8)	58 (-2; -8)	56,3
ESV_4			
Simulation	58 (-2; -6)	58 (-1; -6)	57
ESH_A_4			
Test	58 (-3; -9)	58 (-2; -9)	56,3
ESH_A_4			
Simulation	61 (-1; -5)	61 (-1; -5)	60
ESV_5			
Test	59 (-6; -14)	59 (-5; -14)	54,2
ESV_5			
Simulation	59 (-4; -10)	59 (-3; -10)	56
ESH_A_5			
Test	68 (-4; -10)	68 (-3; -10)	65,2
ESH_A_5			
Simulation	67 (-2; -8)	67 (-2; -8)	65

Table 8. Comparison airborne sound insulation results.

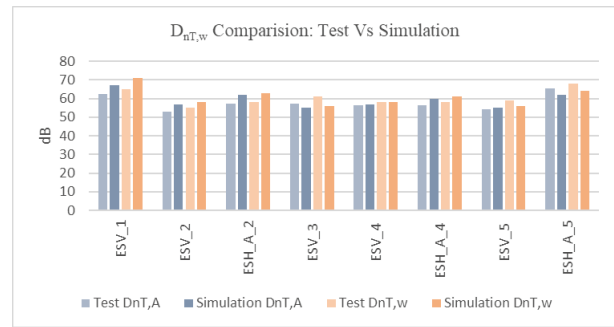


Figure 4. Comparison of airborne sound insulation results.

Regarding the impact sound insulation results, as we can see in table 9 and figure 5, the comparison of the standardized impact sound pressure level, $L'_{nT,w}$, does not present a difference between the *in situ* measurements and the impact sound insulation predictions.

	$L'_{nT,w} (C_i)$ 100-2500
ESH_I_2	
Test	51 (1)
ESH_I_2	
Simulation	51 (1)
ESH_I_4	
Test	51 (1)
ESH_I_4	
Simulation	51 (1)
ESH_I_5	
Test	47 (1)
ESH_I_5	
Simulation	48 (1)

Table 9. Comparison of predicted and measured impact sound insulation results.

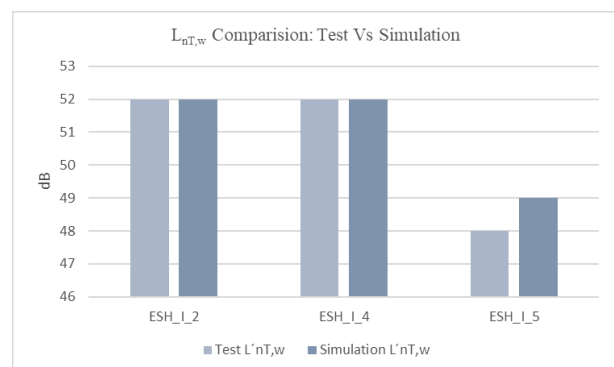


Figure 5. Comparison of predicted and measured impact sound insulation results.

6. CONCLUSIONS

This paper shows a comparative study between *in situ* sound insulation measurements and theoretical predictions.

Five common Spanish housing blocks built according to the current regulations, Basic Document, DB HR, Protection against Noise of the Spanish Building Code, CTE have been studied.

Calculations have been made in accordance with ISO 12354 and field measurements have been carried out in accordance with the standard ISO 16283, parts 1 and 2. In addition, the comparisons between simulations and *in situ* tests have been made based on the standardized level difference, D_{nT} , and standardized impact sound pressure level, L'_{nT} .

Taking into account the data of the separating walls, an increase of D_{nTw} between 0dB and 5 dB is observed in the theoretical calculations. Likewise, D_{nTA} , also suffers a variation between the real test and the theoretical simulation between 1 dBA and 6 dBA.

In addition, according with the data of separating floors, an increase of D_{nTw} between 1dB and 5 dB is observed in the theoretical calculations.

Regarding the impact sound insulation results, the comparison of the standardized impact sound pressure level, L'_{nTw} , does not present a difference between the *in situ* measurements and the impact sound insulation predictions.

Although in this study, results comply with the requirements established in DB HR in protected rooms, $D_{nTA} \geq 50$ dBA and $L'_{nTw} \leq 65$ dB, it can be seen that the predictions are not conservative. Overestimated predictions could cause constructive solutions to be downsized in relation to ensure regulatory compliance.

7. ACKNOWLEDGEMENTS

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