

The Evolution in the Sound Insulation of Spanish Floors. Typical Performance and their Potential for Improvement

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ABSTRACT

In addition to other requirements, floors in multi-storey housing must protect occupants from neighbour noise. In Spain, Basic Document DB HR Protection against noise of the Building Code requires a minimum airborne sound insulation of $D_{nT,A} (\approx D_{nT,w} + C_{100-5000}) \geq 50$ dBA and an a maximum impact sound insulation of $L'_{nT,w} \leq 65$ dB between two adjoining dwellings. However out of the 25,6 million dwellings in Spain, only 0,54 million have been built after the Basic Document DB HR Protection against noise came into force in 2009. During the years the construction of floors has changed in Spain, from the traditional timber floors to the current beam and block floors with cement screed floating floors. This paper explains the evolution in the types and construction of floors in Spain from 1900 to present days and analyses their airborne and impact sound insulation in relation with the current requirements. This paper uses mainly data obtained from measurements. It also focuses on the potential for improvement of floors.

Keywords: Sound insulation, requirements, separating floors

I-INCE Classification of Subject Number: 33, 80, 86

<http://i-ince.org/files/data/classification.pdf>

1. INTRODUCTION

Spanish regulations on sound insulation came into force in 2009, when Basic Document, DB HR Protection against noise[1] was published. This document upgraded the existent sound insulation requirements for new housing and it brought them closer to those existing in other European countries.

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This paper analyses the evolution of different types of Spanish floors from 1900 to present days and their in situ airborne and impact sound insulation in relation to Spanish current requirements. Several technical guides have been published, e.g. [2], [3], on the evolution of slabs, their structural behaviour, their defects and remedial work, but concerning the sound insulation performance only several papers have been published [4], [5], [6], [7] on the performance of traditional floors, but none of them deals with the field sound insulation of floors of Spanish dwellings from 1900's to present times.

The input data for this paper consists on a total of 169 field airborne and impact sound insulation measurements performed in multi-storey housing between 2003 and 2018. Most of the dwellings were located in Madrid Autonomous Community. The tests were performed between living rooms or bedrooms standing one on top of the other. Table 1 shows the number of tests available per period of construction. 58% of the tests were performed on floors which met the current requirements included in Basic Document, DB HR Protection against noise [1]. Some tests were performed according to UNE-EN ISO 140-4 [8] and 7[9]. After the publication of UNE-EN ISO 16283 series, standards UNE-EN ISO 16283 – 1 [10] and 2 [11] were applied.

This paper is part of the pre-normative research carried out by the Quality in Construction Unit at IETcc which assists the Ministry of Infrastructure of Spain in maintaining the Spanish Building Code. After the publication of Basic Document DB HR 10 years ago, field test have been carried out in dwellings with the purpose of collecting data of the acoustic performance of Spanish constructions so as to gain experience to face current regulation challenges, such as low-frequency sound insulation and Acoustic Classification Schemes.

Table 1. Number of test per period of construction analysed in this paper

Period of construction	Number of field tests available	
	Airborne	Impact
1900-1940	11	9
1940-1970	14	18
1970-1981	3	7
1981-2009	4	4
> 2009	51	48
Total	83	86

2. THE EVOLUTION OF SPANISH SEPARATING FLOORS IN BRIEF

Except for emblematic buildings, separating floors in early 20th century buildings were made of timber joists laid every 30-40 cm in average supported by load bearing walls. The space between the joists was often filled with a mixture of rubble, sand and plaster, supported by wooden panels or forming little brick vaults. On top of the various series of rubble layers, the floor finish was installed, which was usually tiled or wooden, as seen in Figure 1, which shows some sketches of most common separating floors in Spanish housing according to the period of construction.

Concrete became popular in Spain in the 1940's, and beam and block floors were widely used in housing. From 1940 to 1970 more than 6,2 million dwellings were built, a 24% of the current building stock[12]. This period corresponds with the expansion of most capital cities in Spain which absorbed the immigration from the countryside to the cities. Housing blocks were built very fast in the absence of structural and acoustic regulations, common beam depths were 180 to 250 mm for a normal 5 m

span supported by loadbearing brick walls. Blocks between the beams used to be ceramic and cement was poured on top. Even they often lacked a load distribution layer according to [2]. The floor finish used to be terrazzo, ceramic tiles or parquet. The average surface mass of this type of floors including the flooring ranged from 300 to 350 kg/m².

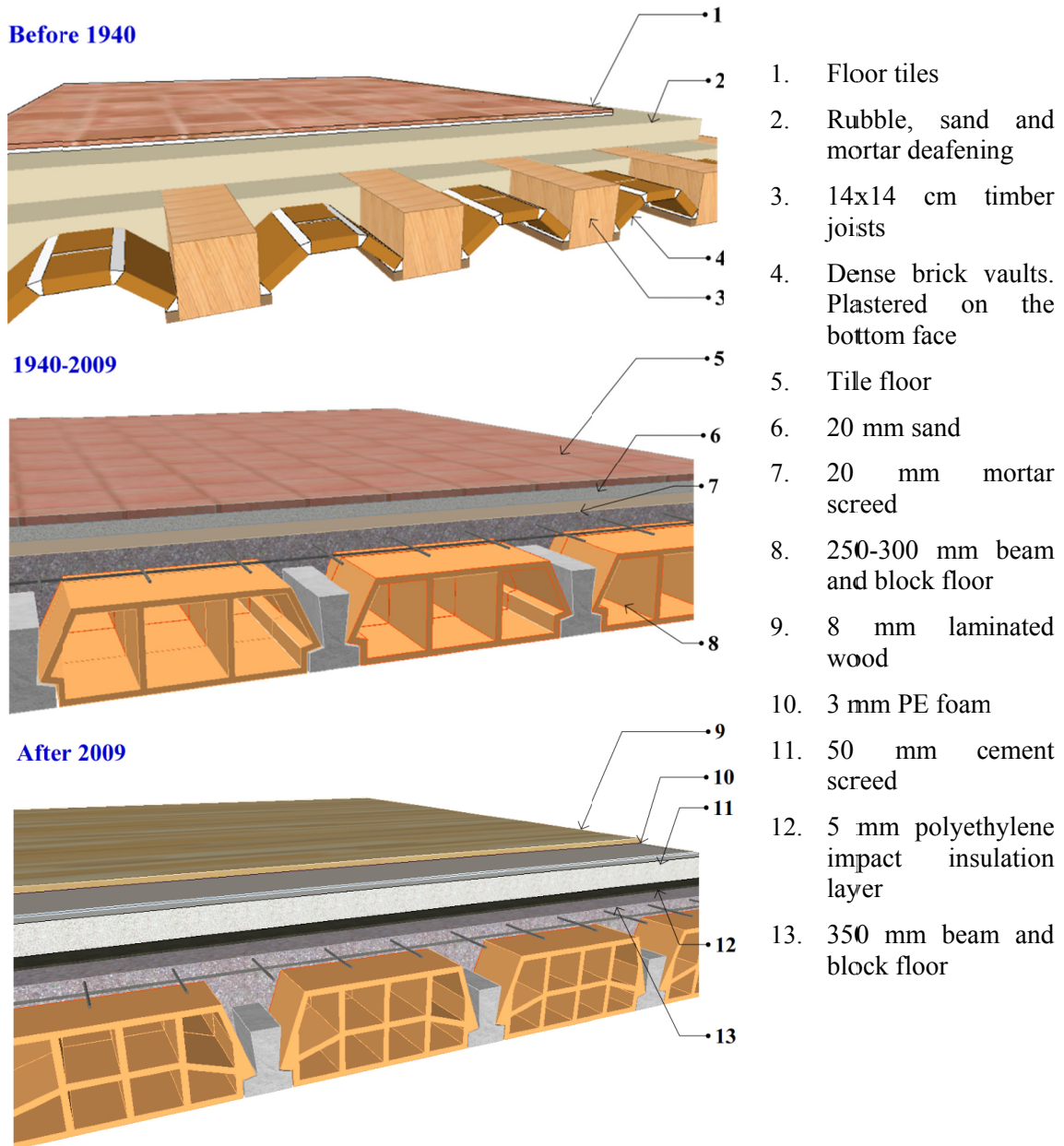


Figure 1. Most common separating floors in Spanish housing according to period of construction

In 1973, EH 73 [13], a regulation for the project and execution of reinforced concrete works, was published, which set the minimum structural requirements for floors. The first regulation on sound insulation, NBE CA – 81[14], came into force in 1981. The sound reduction index for separating floors then was set to be $R_d \geq 45$ dBA and the maximum normalized impact sound pressure level was $L_{n,A} \leq 80$ dBA, expressed as laboratory sound insulation descriptors.

Although in 1988, there were new regulations on sound insulation [15], the requirements for floors were the same. Typical concrete floors of this period are beam and block floors and grid floors with concrete blocks. The depth of the floors used to be 250 mm, the span between the beams was 600 to 700 mm and they had a 50 mm reinforced load distribution layer. A sand layer and a mortar screed were poured before laying the floor finish, which resulted in separating floors with an average mass of 380 to 480 kg/m². Impact sound insulation layers were not installed between the floor finish and the structure. In this period, buildings were composed of a grid structure, were slabs were supported by beams and pillars.

This type of floors were built in housing between 1981 to 2009, which means they are present in approximately 10,78 million dwellings, 42 % of the Spanish building stock .

It was in 2009 when Basic Document DB HR Protection against noise came into force. The minimum airborne sound insulation is $D_{nT,A} (\approx D_{nT,w} + C_{100-5000}) \geq 50$ dBA and the impact sound insulation is $L'_{nT,w} \leq 65$ dB between two adjoining rooms belonging to different dwellings.

Apart from the requirements, Basic Document DB HR Protection against noise included procedures to guide designers. At the same time, first version of Spanish Guidelines for applying Basic Document DB HR Protection against noise [16] was published, which proposed different types of separating floors and walls to comply with the new requirements.

Currently, floor slab construction is similar to those in previous years: 350 mm wide beam and block floors with ceramic or light aggregate blocks, as well as, 350 mm grid floors with light aggregate blocks, are the most common slabs found in housing. What makes a difference between current separating floors and the ones used in previous times is the installation of floating floors to control impact noise. Typical floating floors consist of at least 50 mm cement screed and a resilient layer, the most common resilient layers found in this study are: 5 mm polyethylene, 20 mm mineral wool and 20 mm elastified expanded polystyrene. In addition, suspended ceilings are often installed in new housing to hide electric wiring, thus increasing the airborne sound insulation.

2. AIRBORNE AND IMPACT SOUND INSULATION OF SPANISH FLOORS

Figures 2 and 3 show airborne and impact sound insulation found in the 169 field measurements analysed in this paper. Results in figures 2 and 3 are presented by period of construction and there is an indication of the number of dwellings in the building stock corresponding to each period. The red horizontal axis represents the current requirements for both, airborne and impact sound insulation. In light orange, former requirements of previous regulations, [14-15] are illustrated. Table 2 contains average sound insulation values for floors in each period.

Table 2. Average sound insulation values found in the 169 tests analysed

Period of construction	Airborne sound insulation, $D_{nT,A}$ (dBA)*				Impact sound insulation, $L'_{nT,w}$ (dB)			
	Number of tests	Average	Max.	Min.	Number of tests	Average (dB)	Max.	Min.
1900-1940	11	49	58	37	9	70	80	56
1940-1970	14	47	51	44	18	77	86	72
1970-1981	3	51	51	51	7	76	80	70
1982-2009	4	52	59	46	4	68	79	58
> 2009	51	58	69	49	48	48	64	35

* $D_{nT,A} \approx D_{nT,w} + C_{100-5000}$

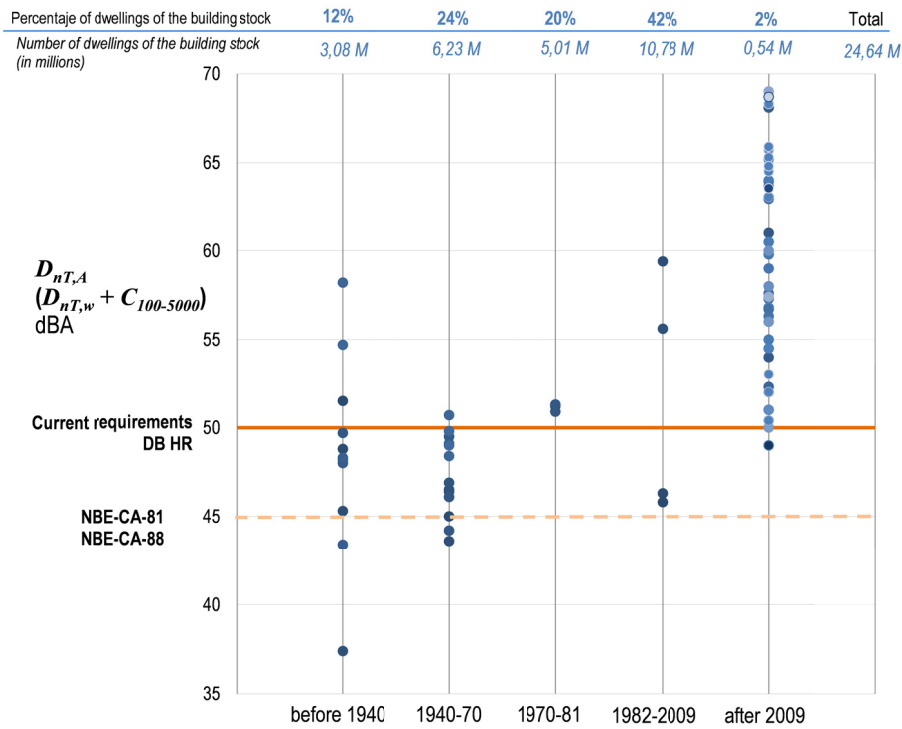


Figure 2. Airborne sound insulation of Spanish floors, expressed as $D_{nT,A} \approx D_{nT,W} + C_{100-5000}$ per period of construction

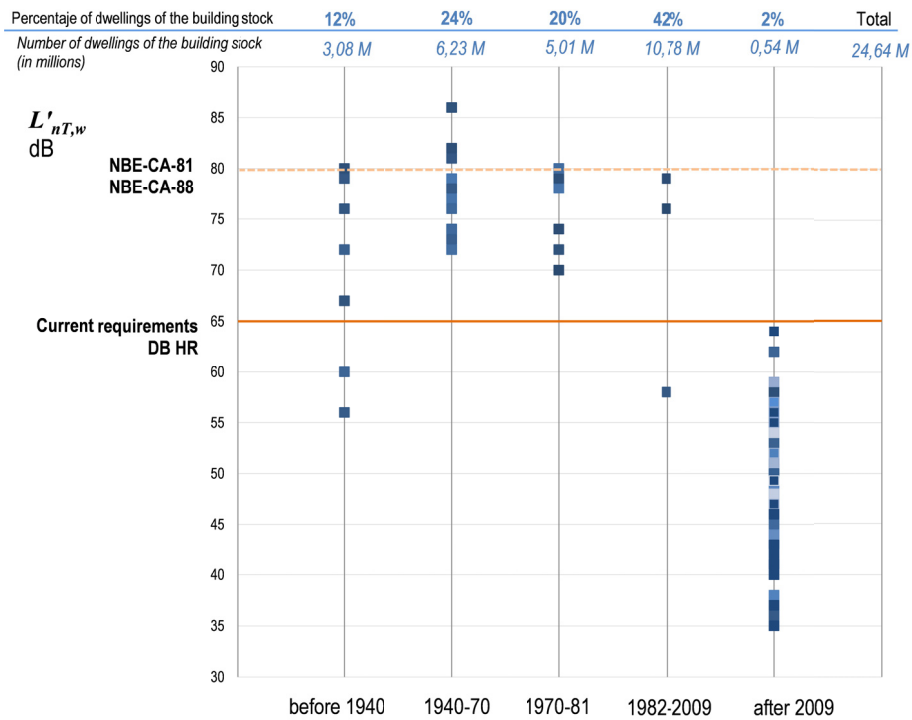


Figure 3. Airborne sound insulation of Spanish floors, expressed as $L'_{nT,w}$ per period of construction

As it can be seen, there is a close correspondence between the airborne sound insulation performance of floors and the period of construction. The same correspondence can be seen for impact sound insulation. With few exceptions, housing

built before 2009, present airborne insulation values lower than 50 dBA, and impact sound insulation values higher than 65 dB.

Sound insulation in early 20th century floors ranges more than 20 dB for airborne sound insulation and 24 dB for impact sound insulation. From 1940 to 1970, airborne sound insulation is lower than in any other period, 47 dB in average, and so is impact sound insulation, 77 dB in average, which is far from the current requirements.

There are not enough field data for the next two periods (1970 – 1981 and 1981-2009), but from the scarce data found, airborne sound insulation increases lightly compared with the preceding period. This corresponds to the approval of regulations on structural safety[13] and acoustics[14]. In contrast, impact sound insulation remains low. This is due to the absence of impact insulation layers in Spanish separating floors.

Next period corresponds to measurements performed in separating floors which complied with the current regulations. Some of the tests were performed before the publication in 2009 of the Basic Document DB HR[1] but were part of the research carried out at the IETcc to determine which construction solutions were to comply with the draft proposals of the regulations.

This group of floors present higher airborne and impact sound insulation than the current requirements, the average value of $D_{nT,A}$ is 58 dBA and the average value of $L'_{nT,w}$ is 48 dB. These values are significantly higher than the limit values set in current regulations. Unfortunately, only 0,53M dwellings, a 2% of the total housing stock, have been built after 2009[17].

3. EXAMPLES OF SOUND INSULATION PERFORMANCE

3.1 Concrete separating floors from 1940 to present days

To illustrate the evolution in the sound insulation of separating floors in Spanish homes built from the 1940's to present days, measurements of a typical beam and block floor have been selected among the 169 test available.

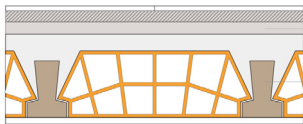
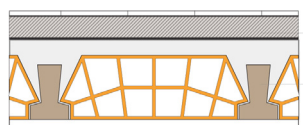
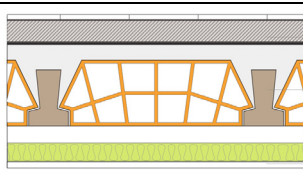
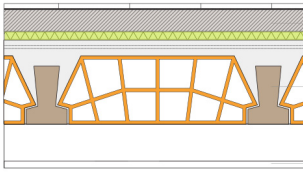
Figures 4 to 7 show the comparison between the field performances of floors built before 2009 and similar floors built after the publication of Basic Document DB HR in 2009. The 12 examples shown were measured in different homes which had a similar concrete beam and block floor. Figures 4 and 7 show the increase in the standardized level difference, D_{nT} . Figures 5 and 7 shows the standardized impact sound pressure level, L'_{nT} , of the same floors.

The differences between the selected solutions consist in the depth of the floor structure and the layers that were installed over the structural floor. The floor structure of floors dating back 1960's was composed of a beam and block floor with ceramic blocks, whose depth ranged 200 mm to 250 mm. They had some layers of mortar and sand, but lack a floating floor and a suspended ceiling. The total depth of the floor was approximately 300 mm.

The structure of floors built after 2009 was 250 mm beam and block floor and a 50 mm concrete load distribution layer. The blocks were ceramic as well. The resilient layers consisted of either a 5 mm polyethylene layer or a 20 mm mineral wool layer. Over the resilient layers, a mortar screed 80 – 100 mm was poured. Finally, the flooring was a laminate over a 3 mm polyethylene layer. In some cases, suspended ceilings were used to hide the electrical wiring. The ceilings were composed of a 15 mm gypsum board and a 50 mm mineral wool layer.

Table 3 shows the details of each floor, the period of construction and a code, which is used also in the figures.

Table 3. Description of the floors measured

	Section	Code	Description
Before 2009		01_(20)_[NFF]	1. 200 mm beam and block floor composed of hollow ceramic blocks. 10 mm plaster on ceiling 2. 70 mm mortar screed and terrazzo
		02_(25)_[NFF]	1. 250 mm beam and block floor composed of hollow ceramic blocks. 10 mm plaster on ceiling 2. 50 mm mortar screed and terrazzo 10 mm
		03_(20)_[NFF]	1. 200 mm beam and block floor composed of hollow ceramic blocks. 10 mm plaster on ceiling 2. 60 mm mortar screed and tiles
After 2009		04_(30)_[FF]	1. 300 mm beam and block floor (25+5), composed of hollow ceramic blocks. 10 mm plaster on ceiling 2. 5 mm polyethylene impact insulation layer under 80 mm mortar screed. Laminate wood flooring over a 3 mm polyethylene layer
		05_(30)_[FF]	
		06_(30)_[FF]	
		07_(30)_[FF]	
		08_(30)_[FF+SC]	1. 300 mm beam and block floor (25+5), composed of hollow ceramic blocks. 10 mm plaster on ceiling 2. 5 mm polyethylene impact insulation layer under 80 mm mortar screed. Laminate wood flooring over a 3 mm polyethylene layer 3. Suspended ceiling composed of 15 mm plasterboard and 50 mm mineral wool layer and 100 mm air gap.
		09_(30)_[FF]	1. 300 mm beam and block floor (25+5), composed of hollow ceramic blocks. 10 mm plaster on ceiling 2. 20 mm mineral wool under 80 mm mortar screed. Laminate wood flooring over a 3 mm polyethylene layer
		11_(30)_[FF+SC]	1. 300 mm beam and block floor (25+5), composed of hollow ceramic blocks. 10 mm plaster on ceiling 2. 20 mm mineral wool under 80 mm mortar screed. Laminate wood flooring over a 3 mm polyethylene layer. 3. Suspended ceiling composed of a 15 mm plasterboard and 100 mm air gap
		12_(30)_[FF+SC]	1. 300 mm beam and block floor (25+5), composed of hollow ceramic blocks. 10 mm plaster on ceiling 2. 20 mm mineral wool under 80 mm mortar screed. Laminate wood flooring over a 3 mm polyethylene layer. 3. Suspended ceiling composed of a 15 mm plasterboard and 50 mm mineral wool layer and 100 mm air gap.

In the figures 4 to 7, different colours are used depending on the period of construction, which also corresponds to differences in the constructions:

- **Black** is used for concrete floors built prior to 2009, these floors had from 50 to 70 mm of sand and concrete poured over the slab to level the floor.
- **Blue** is used for floors built after 2009, which have a 80 mm mortar screed floating floor over a resilient layer consisting in:
 - 5mm polyethylene layer;
 - 20 mm mineral wool layer.

- **Red** is used for floors built after 2009, which have a suspended ceiling composed of a 15 mm gypsum board and an air gap of 100 mm, as well as the same concrete floating floors described in the previous paragraph.

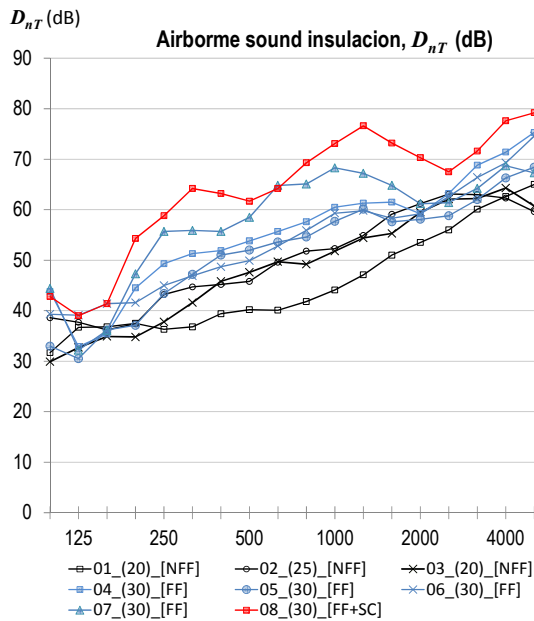


Figure 4. Airborne sound insulation, D_{nT}

Data in blue and red correspond to sound insulation of separating floors with a floating floor over 5 mm polyethylene impact insulation layer

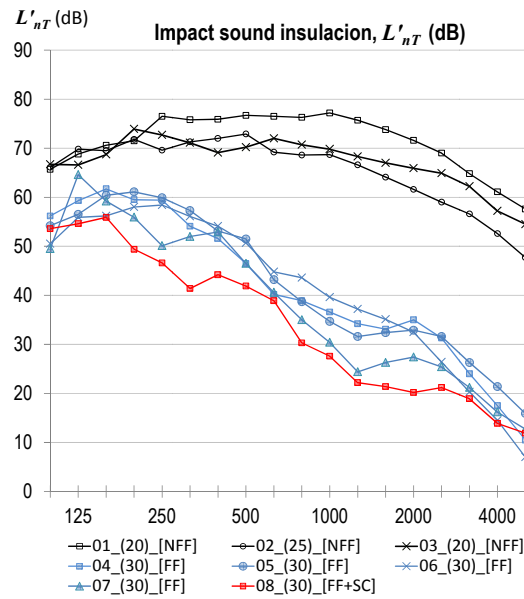


Figure 5. Impact sound insulation, $L'_{nT,w}$

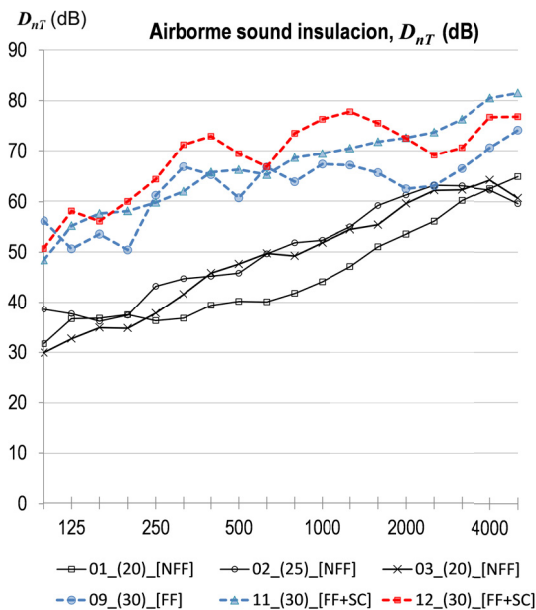


Figure 6. Airborne sound insulation, D_{nT}

Data in blue and red correspond to sound insulation of separating floors with a floating floor over 20 mm mineral wool impact insulation layer

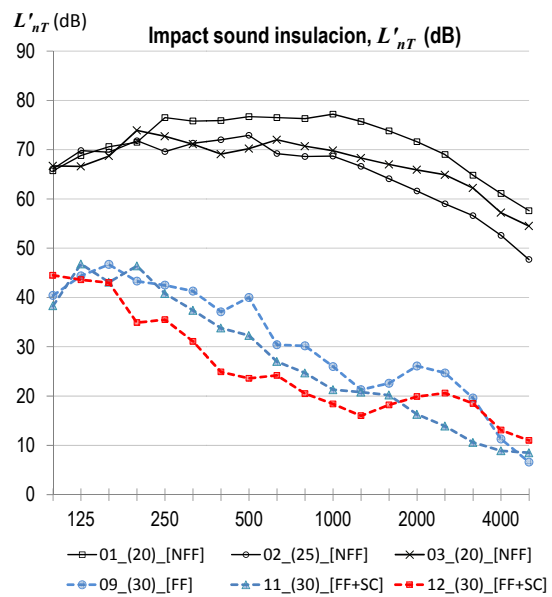


Figure 7. Impact sound insulation, $L'_{nT,w}$

As it can be seen, the examples selected illustrate the increase in sound insulation of separating floors composed of beam and block floors built after 2009 when compared with the performance of typical separating floors built in the preceding decades. The average airborne sound insulation of separating floors which had a PE impact insulation layer was $D_{nT,A} = 54$ dBA, 6 dB higher than the floors built before

2009. In the case of separating floors with a mineral wool impact insulation layer, the increase in the value of the A-weighted standardized level difference was 16 dBA. Suspended ceilings increase the airborne sound insulation as well; results show that the increase is 13 dBA for separating floors with a floating screed over a polyethylene impact insulation layer and a suspended ceiling. Regarding floors with a floating screed over a mineral wool impact insulation layer and a suspended ceiling, the increase in the airborne sound insulation layer is 21 dBA.

Impact sound insulation of both types of separating floors is significantly higher than in the previous periods. From an average of an $L'_{nT,w} = 73$ dB for separating floors built before 2009, to 50 dB and 34 dB for both types of floating floors selected. Values are even higher for the rooms which had suspended ceilings.

Table 4 shows single values of the measurements analysed. It is remarkable that the examples of separating floors built after 2009 meet by far the current limit values of the Spanish Building Code set to be $D_{nT,A} \geq 50$ dBA and $L'_{nT,w} \leq 65$ dB.

Table 4. Airborne and impact sound insulation of the selected 12 examples

Period	Code	$D_{nT,A}$ *(dBA)	$L'_{nT,w}$ (dB)
Before 2009	01 (20+5) [NFF]	45	78
	02 (20+5) [NFF]	51	70
	03 (20+5) [NFF]	49	72
After 2009	04 (25+5) [FF]	54	52
	05 (25+5) [FF]	51	52
	06 (25+5) [FF]	54	50
	07 (25+5) [FF]	57	49
	08 (25+5) [FF+SC]	61	44
	09 (25+5) [FF]	64	37
	11 (25+5) [FF+SC]	69	35
	12 (25+5) [FF+SC]	70	34

* $D_{nT,A} \approx D_{nT,w} + C_{100-5000}$

3.2 Early 20th century separating floors

Approximately 3,08 million dwellings were built before the 1940s. It is unknown which percentage has been retrofitted as these type of buildings have usually undergone several renovations, including the structural reinforcement of the floors. Most common floors were composed of timber joists laid every 30-40 cm, with brick vaults filling the gaps between the beams and several layers of a mixture of sand, mortar and rubble laid on top to level the floor.

Out of the available tests, these floors are the most difficult to describe, as these buildings were very old, there were no written specifications and only in several cases, it was possible to remove part of the sand layers to measure their depth, so the depth of the floors tested was sometimes unknown. Figures 8 and 9 show the $D_{n,T}$ and $L'_{nT,w}$ curves respectively for four examples of traditional floors. The single values of the measurements are presented in table 5. Floors 01 and 02 consisted of a structure formed by 14x14 cm timber joists, separated 300 mm, brick vaults between the joists and a layer of approximately 70 mm of mortar and sand, with terracotta flooring. A suspended ceiling formed by 15 mm plasterboard with no mineral wool inside hid the bottom face of the beams. Floors 03 and 04 were unusually thick, they were formed by 14x23 timber joists, and several layers of mortar, rubble and plaster as deafening, the total thickness of the floors 03 and 04 were approximately 370 m. The tests were made in original floors, that is to say, floors which had not been retrofitted.

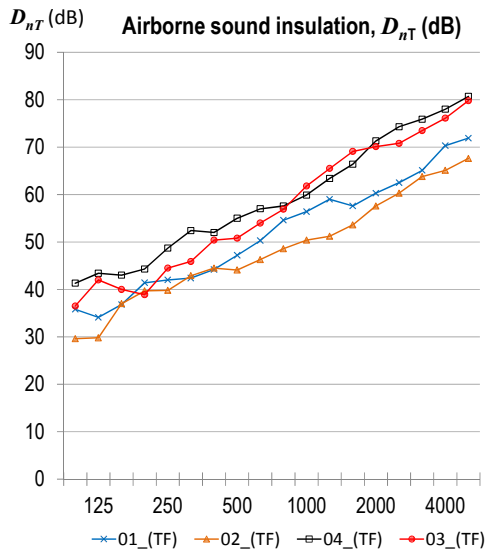


Figure 8. Airborne sound insulation, D_{nT}
Examples of different Spanish traditional floors composed of timber joists and several layers of deafening

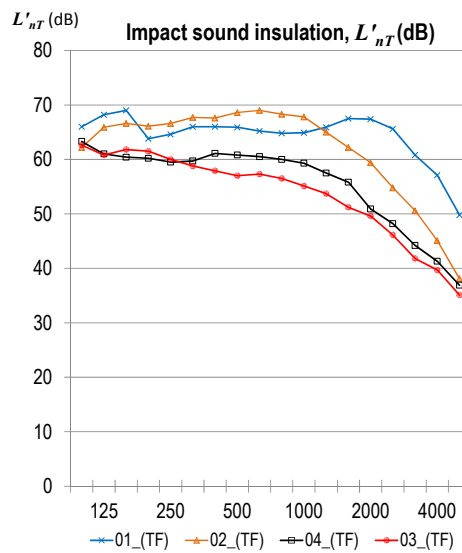


Figure 9 Impact sound insulation, $L'_{nT,w}$
Examples of different Spanish traditional floors composed of timber joists and several layers of deafening

Table 4. Airborne and impact sound insulation of the selected 4 examples

Period	Code	$D_{nT,A}$ *(dBA)	$L'_{nT,w}$ (dB)
Before 1940's (Traditional timber joist floors)	01 (TF)	52	72
	02 (TF)	49	67
	03 (TF)	55	58
	04 (TF)	58	60

* $D_{nT,A} \approx D_{nT,w} + C_{100-5000}$

As it can be seen in table 4 and figures 8 and 9, there is a big variation in the sound insulation of these floors, depending on their composition, e.g. thickness of the deafening layers. The sound insulation of floors 03 and 04 is exceptionally good, in comparison with the sound insulation of floors 01 and 02.

Their possibilities of retrofitting have been analysed in previous papers, such as [5] and [18, Ch. Spain]. The main reason for retrofitting is often the structural consolidation of the timber beams. After that, new floor coverings and suspended ceilings such as the ones described in the previous section can be installed to reach the required sound insulation.

4. CONCLUSIONS

This paper analyses 169 airborne and impact sound insulation tests performed on floors in Spanish homes located in the Madrid Autonomous Community. The sound insulation performance of floors has been studied according to the period of construction.

There is a correspondence between the construction techniques, regulations and the in situ sound insulation performance. Except for some cases, housing built before 2009, present airborne insulation values lower than 50 dBA, and impact sound insulation values higher than 65 dB.

Early 20th century floors were timber joisted, with several layers of a mixture of rubble, mortar and sand. Airborne and impact sound insulation depend on the thickness of these layers. With the available data, it is difficult to define the typical sound insulation performance of this kind of floors, as the in situ airborne and impact sound insulation values analysed vary significantly.

Concrete beam and block floors started to be used in the 1940's. First constructions had a very low airborne and impact sound insulation (average values found were $D_{nT,A} = 47$ dBA and $L'_{nT,w} = 77$ dB). New structural and acoustic requirements in the 1980's resulted in a better airborne sound insulation, but still, the impact sound insulation was poor, as it was not common to install resilient layers underneath the flooring.

It is remarkable how the approval of the Basic Document DB HR Protection against noise has contributed to the increase of field sound insulation in new build housing. Of the tests studied, 62,7% present a $D_{nT,A}$ over 55 dB, 5 dB higher than the requirements. The increase is even better for the impact sound insulation where 85 % have a $L'_{nT,w}$ lower than 55 dB, 10 lower than the requirements.

Basic Document DB HR set requirements but also offers guidance to designers, such as a simplified method to choose partitions and floors. In addition, *Guidelines for applying Basic Document DB HR Protection against noise*[16] contain examples and junction details. Both documents were developed as robust methods for conservative cases. When these methods are followed during the design and construction phases, in situ test results are better than the requirements.

On the other hand, only 2% of the building stock meet the current requirements and except for major restorations, works in existing buildings do not have to meet current acoustic requirements. In dwellings, most typical works are the renovation of finishes and the distribution of the rooms, but little attention is paid to acoustics. The examples of this paper show that installing floating floors and suspended ceilings increases sound insulation to the required limit values.

5. ACKNOWLEDGEMENTS

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