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Airborne and impact sound insulation performance in Spanish multi-storey housing: 10 years of the protection against noise regulations in the Building Code (2009-2019)

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ABSTRACT

This paper presents the acoustic performance of multi-storey housing for the different construction systems considered in the Basic Document DB HR Protection against noise of the Building Code. It focuses on airborne and impact sound insulation in interior walls and floors. Shown data comes from acoustic insulation tests made during these ten years of the validity of acoustic regulation in Spain. This way the degree of compliance with the acoustic requirements established is checked and, in addition, a comparison with the corresponding acoustic class is done according to the draft of the standard of acoustic classification of dwellings in Spain (PNE 74201), still under development.

Keywords: Sound Insulation, Spanish Building Code, Acoustic Classification
I-INCE Classification of Subject Number: 33, 80, 86.

1. INTRODUCTION

The aim of this study is to define the airborne and impact sound insulation properties of Spanish new buildings since the application of DB HR [1] ten years ago so as to establish whether constructions satisfy the requirements established. The study focuses in interior walls and floors in dwellings.

The DB HR is the regulatory framework for building acoustics within the Building Code in Spain [2]. It was published and came into force in April 2009 and it meant a huge and important change in regard to the previous regulation (NBE-CA-88 [3]) that, in addition to regulating lower insulation values, it did so by using parameters based in laboratory tests of the building elements. DB HR is a performance code and, besides applying higher sound insulation requirements, it uses in situ insulation descriptors to regulate the acoustic performance once the building is finished.

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When DB HR came into force in 2009, according to social surveys conducted annually, 22,4% of homes acknowledged they were disturbed by either neighbour noise, or outdoor noise. The latest surveys indicate that in 2017 this figure is at 15,2% [4]. Another important fact in 2009 was that Spanish construction industry was suffering a strong crisis with a sharp decrease in the number of new built homes. It is estimated that, in the period 2010-2017, just over half a million homes were built in Spain [5].

This year this regulation has reached 10 years in force. During this time, in situ tests have been carried out (and they are still being done) to gather results, within the pre-normative research work carried out in the Institute. For the fulfilment of this works it is fundamental the cooperation of building industry promoters and constructors that allow their buildings to be tested.

This data collection was initially proposed to:

- Verify the degree of compliance with the acoustic requirements;
- Detect problems in the application of DB HR, execution conditions, for instance, that make it difficult to reach the requirements;
- Create an increasingly size data base of building acoustics measurements and performance;

As new more recent objectives we have:

- Gain experience with low frequency sound insulation measurements procedure [6] and study the performance of typical constructive solutions taking them into consideration;
- Acoustic classification scheme. In Spain, a UNE standard on acoustic classification of buildings is being drafted, compatible with Spanish regulations but as faithful as possible to the ISO standard [7, 8], resulting from the proposals of the European project COST TU 0901 [9]. It is necessary to analyse how our buildings and usual constructive solutions would be classified according to this Spanish scheme.

Therefore, in this paper several data are analysed: on the one hand, the airborne and impact sound insulation performance of buildings that have been built according to the DB HR is studied and, on the other hand, a comparison of the results with the acoustic classification scheme of dwellings in Spain (PNE 74201 [10], under development) is done.

Almost all available data correspond to multi-family houses, and is that, in relation to the type of dwelling, 66,1% of Spaniards live in flats compared to 33,5% who live in detached/semi-detached houses, which makes Spain the European country with the highest proportion of people living in flats (2016 data) [11]. This type of housing is usually the most available to make acoustic studies; the typology of the constructive solutions is shown in section 2.2.

2. THE PROTECTION AGAINST NOISE DOCUMENT (DB HR)

The DB HR set new acoustic requirements for design and construction of new buildings and major restorations. The required sound insulation increased, and consequently also the quality of Spanish dwellings. Also, since then the acoustic performances are demanded to the rooms in finished buildings instead of to each one of the constructive elements. These sound insulation requirements are expressed by single-number quantities referring to field standardized measurements that are directly comparable to the required limit values. Although acoustic tests are not prescribed in a mandatory way in DB HR, it does indicate the way in which the measurements and the rating of sound insulation must be made. In any case the measurements may be required by one of the agents of the building and can also be required by municipal regulations (we already have some cases in Spain).

2.1 Sound insulation requirements

Sound insulation descriptors used in Spanish regulations are $D_{nT,A}$ (100-5000 Hz) for airborne sound insulation and $L'_{nT,w}$ (100-3150 Hz) for impact sound insulation. Table 1 shows airborne and impact sound requirements in a simplified way.

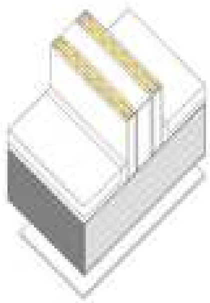
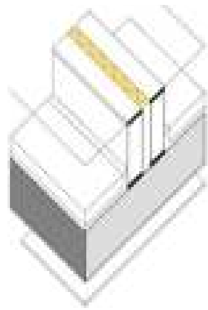
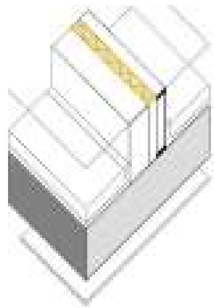
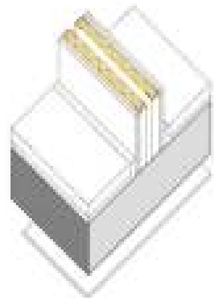
Table 1. Airborne and impact sound insulation requirements according to DB HR 2009.

Type of space	**Airborne sound insulation between different dwellings**	**Impact sound insulation between different dwellings**
Between protected rooms, such as bedrooms, living rooms, classrooms	$D_{nT,A} \geq 50$ dBA	$L'_{nT,w} \leq 65$ dB
Between habitable rooms, such us kitchens, bathrooms, halls, corridors, etc.	$D_{nT,A} \geq 45$ dBA	None
Between protected rooms and equipment or activity rooms	$D_{nT,A} \geq 55$ dBA	$L'_{nT,w} \leq 60$ dB

2.2 Construction types for separating walls and floors

In Spain with the current DB HR, three construction types are used for separating walls. As for separating floors, the variability of constructive solutions is given by the type of floating floor that is installed, which is practically obligatory to meet the requirements. Construction types for partitions between dwellings in multi-storey housing in Spain, proposed by Building Code, are shown in Tables 2 and 3.

Table 2 Separating walls types [12]

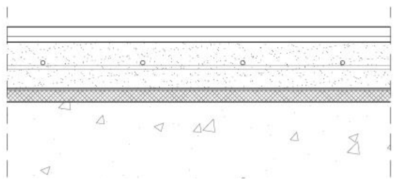
Type 1: Masonry between independent linings Single leaf masonry walls with one (1B) or two (1A) layers of gypsum boards fixed to independent steel frames.	**Type 2: Heavy cavity walls** Masonry cavity walls with elastic layers which are placed on top of cavity separating walls to limit the flanking transmission along the floor and ceiling.	**Type 3: Light steel frame walls** Two leaf gypsum based board walls consisting of two plaster boards directly screwed to double metal studs and with absorbent material batts placed between the studs.
	 Type 2A  Type 2B	

There are two options in Type 2 separating walls:

- 2A: Double hollow light ceramic wall with both leaves resting on expanded elastic polystyrene (EEPS) bands;
- 2B: Solid ceramic wall rigidly attached to the floor and a hollow light ceramic wall with acoustic elastic layers in its perimeter (EEPS).

As for separating floors, most common floors in Spain are beam and blocks floors (with either ceramic or light aggregate concrete blocks) and grid floors. To meet the demands on impact noise insulation, the use of floating floors is extended. And in some cases it is necessary the use of suspended ceilings to reach airborne noise requirements. Three types of floating floors are commonly used which are listed in Table 3. In all cases a resilient layers is interposed, typically mineral wool, polyethylene and expanded elastic polystyrene (EEPS) and a floor finish is installed on top.

Table 3 Floating floor types in separating floors

Floating floor 1: Cement mortar screed	
Floating floor 2: Plasterboard screed	
Floating floor 3: Laminate flooring	

Finally, a brief mention to the internal walls which are selected in a coherent way in the project according to whether they are masonry walls or light steel frame walls.

3. ACOUSTIC CLASSIFICATION SCHEME

Building regulations specify minimum requirements in protection against noise that every new building must comply with. However, there is a great potential to achieve enhanced acoustic insulations, which will result in better acoustic conditions for occupants in an increasingly demanding society of acoustic comfort for their dwellings.

An acoustic classification scheme would indicate different ranges of acoustic comfort and according to the assigned class it would suppose an added value for the buildings being, somehow, a mechanism to encourage the construction of acoustically improved buildings.

There are already a few countries that have an acoustic classification scheme in Europe [13]. The European project COST TU 0901 worked, a few years ago, in a harmonized acoustic classification scheme for dwellings proposal and the TC43/SC2/WG29 tried to continue the work to develop an ISO standard on acoustic classification.

In Spain, after 10 years of application of DB HR, experience has shown that most of new constructed buildings meet the sound insulation requirements and, sometimes, even with a wide margin. An acoustic classification scheme, regardless of whether it is regulatory or not, would imply a commitment to improve the acoustic quality of buildings in our country, above the legal requirements.

A working group was created, within the structure of AENOR CTN 74/SC2, to work on an acoustic classification scheme for Spain, inspired by the COST and ISO standard proposals but compatible with DB HR regulations. The members of this group, active as today, are experts who belong to the sectors of university, building research institutes, administration, laboratory and manufacturing.

In the Spanish scheme draft criteria for 6 acoustic classes are specified (A, B, C, D, E and F - A is the upper and F is the lower class) and the scope applies to private and public residential buildings, whether they have several flats or they are detached and attached dwelling houses, and for hospital and health buildings and educational use as well.

Due to the fact that the standard is still being drafted, only the values of the class limits for airborne noise and impact sound insulation in protected rooms (for instance, bedrooms and living rooms) between different users will be shown, which are those related to the data that will be exposed in the following sections of this paper. Sound insulation descriptors used are those used in DB HR, that is, $D_{nT,A}$ for airborne sound and $L'_{nT,w}$ for impact sound insulation. The frequency range used for sound insulation assessment is 100-5000 Hz for airborne and 100-3150 Hz for impact sound insulation. The values for class limits are explained below.

Table 4 Class limits for airborne and impact sound insulation between dwellings or units of different use (protected rooms).

Type of rooms	Class A	Class B	Class C	Class D	Class E	Class F
Protected rooms between different users in all directions	$D_{nT,A} \geq 60$	$D_{nT,A} \geq 56$	$D_{nT,A} \geq 54$	$D_{nT,A} \geq 50$	$D_{nT,A} \geq 46$	$D_{nT,A} < 46$
	$L'_{nT,w} \leq 50$	$L'_{nT,w} \leq 55$	$L'_{nT,w} \leq 60$	$L'_{nT,w} \leq 65$	$L'_{nT,w} \leq 70$	$L'_{nT,w} > 70$

According to the above values it can be seen that the buildings that comply with the limit values of the DB HR are class D and buildings with insulation performance below a certain value would correspond with class F.

4. SOUND INSULATION MEASUREMENTS

4.1 Test scenarios

The data used come from experimental results obtained by sound insulation measurements (most of them done by the authors) in new residential buildings that have been built according to CTE-DB HR. There is one case with an office building and another case of acoustic chambers that simulate field conditions (indirect transmissions) to test different combinations and configurations of constructive solutions. 53 separating walls and 35 separating floors have been measured.

Field airborne and impact sound insulation measurements have been developed involving the three different types of separating walls and different combination of floor, floating floor (SF) and suspended ceiling (TS) for separating floors.

In general, measurement data of this study are referred to protected rooms. The measurements analysed include: airborne sound insulation, 53 in separating walls and

33 in separating floors; impact sound insulation, 32 in separating floors. Percentages of different type of constructive solutions are shown in Figure 1.

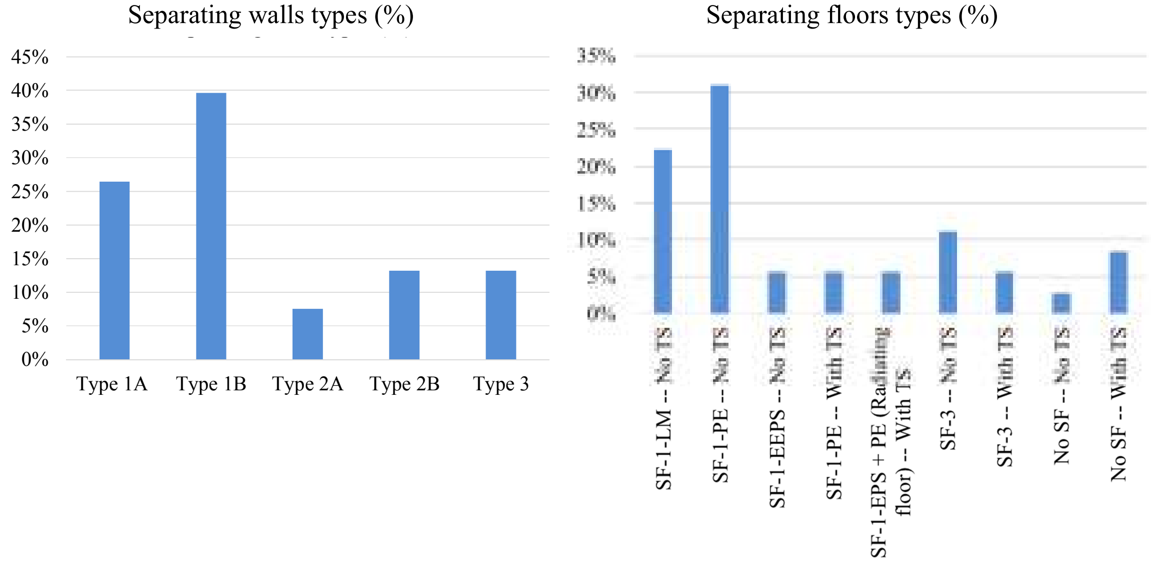


Figure 1. Percentages of separating walls/floors according to construction type.

In separating walls Type 1B cases, those with only one lining, correspond to mostly adjoining common areas such as stairs. As for separating floors, the resistant parts are mainly grid floors with concrete blocks (23). The others are beamed floors with ceramic blocks (5), EPS blocks (5) and concrete blocks (2). As for its thickness, approximately half are 25+5 cm and the other half are 30+5 cm.

4.2 Measurement methodology

Sound insulation measurements were carried out according to UNE-EN ISO 140-4 [14] and 7 [15]. Since UNE-EN ISO 16283-1 [16] and 2 [17] drafts appeared, they also began to be used in measurements, to collect data from the frequency of 50 Hz. In any case, for the purposes of this work it is considered that the results obtained by UNE-EN ISO 140 and UNE-EN ISO 16283 (default method) are equivalent in the frequency range studied (100-5000 Hz). Regarding the evaluation of sound insulation third-octave band spectra by single-numbers, UNE-EN ISO 717-2 [18] is referred for impact sound insulation ($L'_{nT,w}$) and Equation 1 is used to obtain airborne noise insulation ($D_{nT,A}$), using the A-weighted pink noise spectrum (L_{Ar}), according to the indications of DB HR. It's considered that $D_{nT,A}$ is equivalent to $D_{nT,w} + C_{100\text{-}5000}$ in UNE-EN ISO 717-1 [19].

$$D_{nT,A} = -10 \cdot \lg \sum_{i=100}^{5000} 10^{(L_{Ar,i} - D_{nT,i})/10} \quad [\text{dBA}] \qquad (1)$$

Some of the criteria considered when making the measurements were the following ones:

- Measurements were only made in one direction, not bidirectional;
- It was considered that the receiving room was the one with the lowest volume;
- In the measurements of separating floors, the upper room was considered as the source room, both for airborne and impact sound insulation;
- Most of the separating floors were impact sound tested vertically, although some horizontal tests were also carried out.

5. SOUND INSULATION PERFORMANCE. COMPARISON WITH BUILDING REGULATIONS AND WITH ACOUSTIC CLASSIFICATION SCHEME.

This section shows the results of the acoustic insulation tests carried out for separating walls and floors; the compliance or failure rates of the requirements and their corresponding acoustic classes are analysed in accordance with the previously presented values.

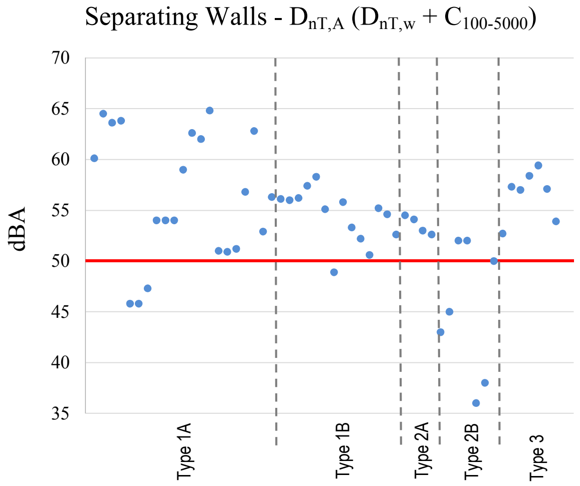
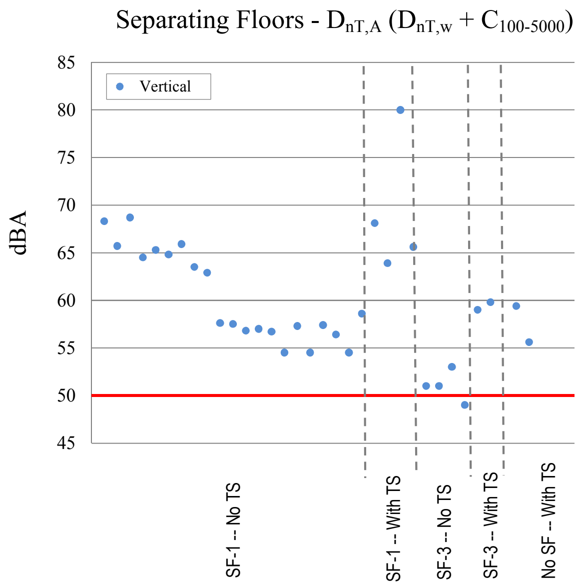


Figure 2. Separating walls-Graphical presentation of airborne sound insulation measurements results.



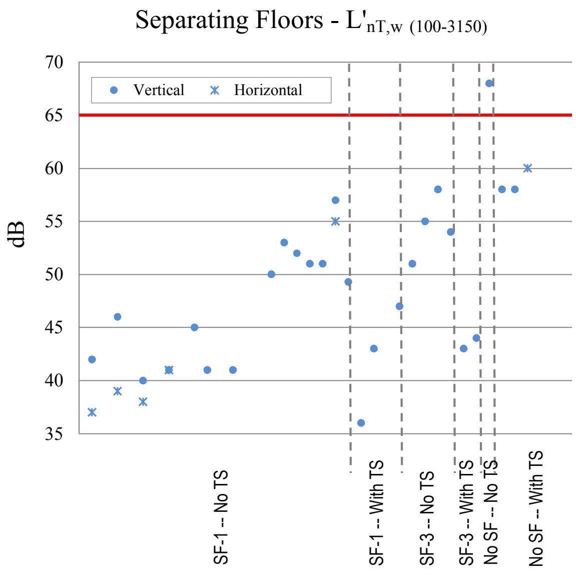


Figure 3. Separating floors-Graphical presentation of airborne (left) and impact (right) sound insulation measurements results.

In relation to separating walls, measurement data collected have been grouped for analysis according to the three different types of constructive solutions proposed in the DB HR (Figure 2). As for separating floors, measurement data collected have been grouped for analysis depending on the different floating floor solutions that they have installed as well as the existence or not of suspended ceiling (Figure 3).

In view of the previous graphs we can say that there is a high degree of compliance with the requirements in all cases. In the case of separating floors, cases of non-fulfilment are practically exceptional situations. In separating walls, there are more cases in which the requirements are not met but these are focused on the test cases of different configurations of constructive solutions made in the acoustic chambers that simulate field conditions. In real constructed buildings measurements the degree of compliance is almost total.

In the acoustic classification scheme draft, the idea is that verification of classes is not only done of an entire building but also individual dwelling or individual acoustic characteristics. For the purposes of this work, the comparison of the results with the acoustic classes is done individually, based on each of the tests and the constructive typology to which it belongs to. Figures 4 and 5 show the resulting class assignments.

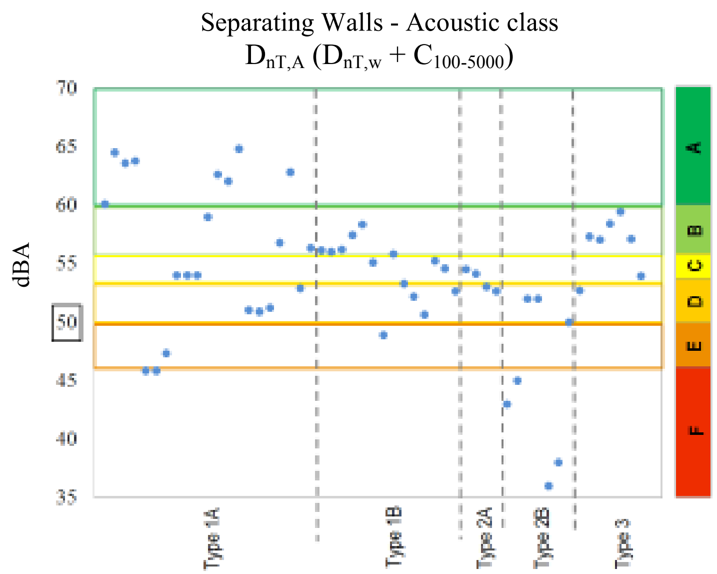


Figure 4. Separating walls-Graphical presentation of airborne sound insulation measurements results and indication of acoustic classes.

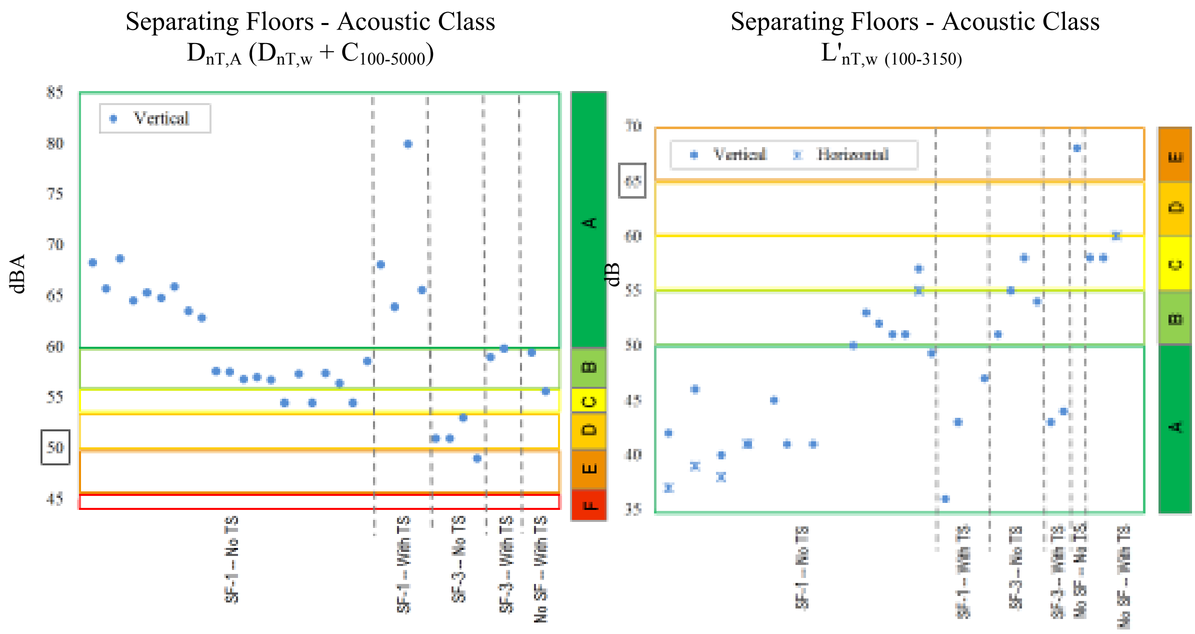
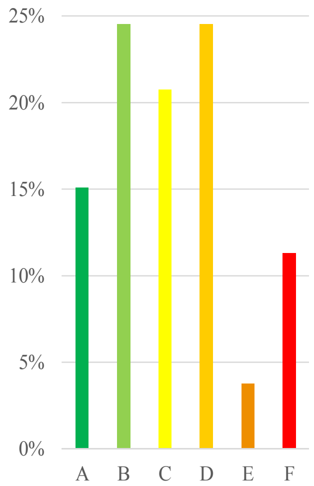
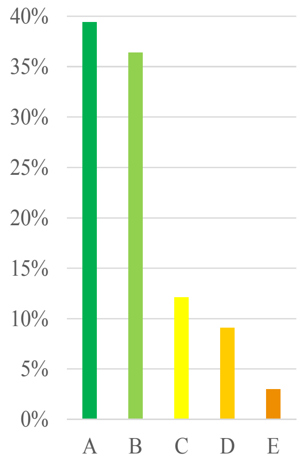
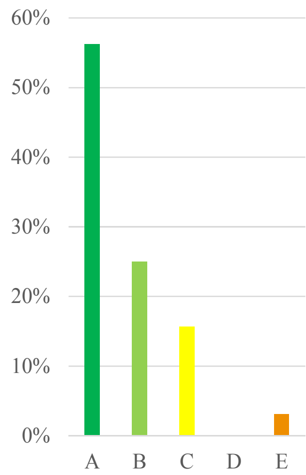


Figure 5. Separating floors-Graphical presentation of airborne (left) and impact (right) sound insulation measurements results and indication of acoustic classes.

The summary Table 5 presents the number of measured data and the percentage of compliance/failure by considering the threshold values by Spanish requirements; the proportion of each class assigned within the tests carried out is also shown.

Table 5 Class limits for airborne and impact sound insulation between dwellings or units of different use (protected rooms).

		Separating Walls - Acoustic Class $D_{nT,A}$ ($D_{nT,w} + C_{100\text{-}5000}$) 	Separating Floors - Acoustic Class $D_{nT,A}$ ($D_{nT,w} + C_{100\text{-}5000}$) 	Separating Floors - Acoustic Class $L'_{nT,w}$ (100-3150) 
No. tests		53	33	32
Req.		$D_{nT,A} \geq 50$ dBA	$D_{nT,A} \geq 50$ dBA	$L'_{nT,w} \leq 65$ dB
Fulfilled	Yes	84,9% (45)	97,0% (32)	96,9% (31)
	No	15,1% (8)	3,0% (1)	3,1% (1)

6. SUMMARY

In Spain, 10 years have passed since the entry into force of the current building regulations with respect to building acoustics (DB HR in the Spanish Building Code). These regulations use higher requirements for acoustic insulation and, in turn, it's made so by means of in situ descriptors comparable with measurements. On the other hand, Spain is working on an acoustics classification scheme, as a new challenge in the near future, that would inspire and encourage the acoustic quality of buildings beyond the regulatory requirements.

The achievement of compliance of DB HR implied some changes and it meant also a significant improve in Spanish traditional construction techniques. For instance, separating walls solutions that were used were insufficient to meet the new requirements and two leaf light steel frame walls and heavy cavity walls with elastic layers began to be used. In separating floors the use of floating floors is now extended in order to meet impact sound requirements and sometimes the installation of suspended ceilings is also required to reinforce airborne noise insulation.

Throughout this time, acoustic insulation measurements have been carried out on newly constructed buildings, in accordance with these regulations, which results have been presented in this paper.

In summary, it is concluded that the sound insulation requirements in the current building regulations in Spain are fulfilled in most cases. The acoustic performances that merely fulfil the requirements position our buildings in class D within the acoustic classification scheme draft. When the constructive solutions for walls and floor were proposed in DB HR, it was done thinking about reaching the regulated limit values; however, as it has been proved and shown, it is possible to achieve better acoustic insulation performance both for airborne noise and for impact noise and for both separating walls and floors.

In the case of separating walls, the proportions of classes B, C and D are very even (21-25%); class A (15%) has only been reached with Type 1A solutions (double lining), at least with the available data. As for separating floors, in relation to airborne sound insulation, 75% of them cover classes A and B; and focusing on impact sound insulation, most of the samples tested are class A (56%), only 3% is below class C and there is no class F, what could be interpreted as the requirement is somewhat moderate and could be higher in a future.

Finally, it is essential to continue with this type of work that can in some way have an effect on the acoustic comfort of all building users. It is important that the test sample be extended as much as possible in order to characterize, as accurately as possible, the acoustic performance of our usual construction systems as well as to analyse their potential for improvement. Future research should also consider the low frequency margin in the measurements and data analysis, which will be the subject of coming works.

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