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The development of a Spanish Acoustic Classification Scheme for residential, sanitary and docent buildings: Challenges and potential impact

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ABSTRACT

Sound insulation requirements for buildings have existed in Spain since 1981, although it has not been until 2009 when such regulations have been upgraded and modified to correspond to the acoustic performance of the building. Ten years later a new challenge knocks on the door of the Spanish building sector: the development of an acoustic classification scheme for private and public residential buildings as well as sanitary and docent buildings. This paper deals with the development of the PNE UNE 74201 (Acoustic Classification Scheme for Buildings) and includes an analysis of the potential impact on the Spanish building sector as well as recommendations for the future update of the existing regulations.

Keywords: Building Acoustics Regulations, Acoustic Classification Scheme
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1. INTRODUCTION

It is undoubtable that unwanted sound in our everyday life disturbs and affects our moods and even our health, no matter whether we are indoors (home, work, leisure, studying…) or outdoors (streets, parks, beach, mountains…) [1,2]. This is and has always been a fact since mankind exists, but unfortunately it has not always been properly recognized and addressed.

It is estimated that in the so called "developed countries" we spend approximately 90% of our lives indoors [3–5]. This fact is widely accepted to be a "health related issue" considering air pollution, lack of exercise… but surprisingly, noise pollution indoors is seldom considered as a health issue.

Considering the built environment (indoors), the first regulation on building acoustics was published in Spain in 1981 (NBE- CA 81) and later revised in 1982 and 1988 [6]. Unfortunately this document was rather a "descriptive code", which stablished acoustic requirements to the building elements according to laboratory tests and thus this first attempt to protect the end user from noise was not very successful.

Twenty one years later and after 12 years of conversations (from 1997 to 2009) between all the interested and affected agents (Architects, Professional Associations, Constructors, Product Manufacturers Associations, Building Industry Promoters, Building Acoustics Research Groups, Universities…) a new building acoustic regulation came into force: the DB HR- Protection against noise [7]. The development of DB HR meant having to deal with a large part of the sector, fundamentally architects and promoters who looked at it with rejection. The final normative document, in force since 2009, was revolutionary at that moment: increasing the sound insulation requirements and using in situ sound insulation descriptors was a great breakthrough. The DB HR is a performance code, focused on "what has to be achieved" once the building is finished. All the details about the making of the DB HR Spanish Noise Protection Building Code can be found in [8].

It is interesting to bear in mind that the DB HR came into force in the middle of the economic and construction sector crisis and with figures for the construction of new buildings well below previous years, with a steep fall of 82% in new construction visas compared to the year 2007 [9]. It is estimated that in the period 2010-2017 about half a million new dwellings were built. This means that, in spite of the legislative efforts made, most of the Spanish population still lives and works in buildings with low protection against noise, with an estimated airborne sound insulation of $D_{nT,A} \leq 40$ dBA on average [10]. It can be said that the existing building stock in Spain is still quite obsolete with a low level of conservation and, in general, with poor acoustic performance. This is because more than 75% out of the 18 millions of existing primary homes was built before the approval of the aforementioned NBE-CA-88 and nearly 95% before the enforcement of the DB HR [11].

Nowadays, the DB HR can be considered "mature" after 10 years of enforcement. The experience has shown that most of buildings constructed under the DB HR regulations meet the sound insulation requirements without problem. If airborne sound insulation is considered, the requirements' fulfilment is achieved with more or less margin depending on the construction system, but concerning impact sound insulation, the measured values almost always significantly exceed the requirements. Therefore, it is the right moment to introduce a new tool for constructors and users to adequately understand the acoustic performance and quality of residential, docent and sanitary spaces. This tool is the purpose of this paper: The Spanish Acoustic

Classification Scheme (Spanish ACS hereinafter). As of February 2019 the document is still under drafting and shall be referred to as PNE 74201.

2. BACKGROUND

Back in 2010 an overview of existing building acoustics descriptors and requirements included in building acoustics regulations in Europe was published [12,13]. It was found that a great variety of descriptors and requirements were used. Over the coming years, there was a strong interest in knowing how the state of the building acoustic regulations in Europe was. Which countries had developed an Acoustic Classification Scheme? What were the differences between existing acoustic classification schemes? Did the regulations include procedures to improve acoustic design, to verify compliance with existing requirements or to place a complaint? Most of the answers to these questions have been answered in different papers [14–16].

Almost simultaneously, between 2009 and 2013 a European project, COST TU 0901 [17], was launched and aimed (among other things) at developing a harmonized proposal for building acoustic descriptors and drafting an acoustic classification scheme.

One of the outputs of all the work developed within COST TU 0901 was a harmonized acoustic classification scheme for dwellings which can be found in section 5.4 of reference [18]. This proposal was in turn used as a first draft by ISO TC43/SC2/WG29 to develop an ISO ACS standard, but for different reasons the project is still under development [19,20].

In the meantime, in Spain the building sector and product manufacturers showed a strong interest in having an acoustic classification scheme for dwellings compatible with the Spanish regulations (DB HR) and asked the building acoustics committee CTN 74 from the Spanish Standardisation Board to develop it. A working group (GT1) was stablished with experts from different sectors such as product manufacturers, laboratories, universities, building research institutes and administration. Just as ISO had done, the CTN 74/SC2/GT1 used as first draft the COST TU 0901 proposal and the subsequent the revisions made by the corresponding ISO working group (WG29). One of the intentions within GT1 while developing the Spanish ACS was to remain as close as possible to the ISO ACS proposal, but still compatible with the Spanish regulations. It was agreed that the Spanish ACS would have the same formal structure and the same number of classes (A for the upper and F for the lower) as the ISO ACS proposal.

Developing a standard is a “voluntary” unpaid task. In most cases the work load of the experts is not considered by their corresponding employers, so the work has to be done during weekends or holidays. This reality has delayed the development of the PNE 74201. The kick off of the GT1 was in September 2016 and when writing this paper it is expected that the Spanish ACS will be published as UNE 74201 before the end of 2019.

3. CHALLENGES AND CORRESPONDING ADOPTED POSITION

While developing the Spanish ACS, the experts in the working group (GT1) have encountered many different administrative and technical challenges. For future users of the standard it might be interesting to be aware of which have been the most critical points and how the working group has dealt with them. Before presenting a summary of the most relevant past and future challenges, it is necessary to point out that often these challenges have been directly related to the fact that the outcome had to be consistent with the Spanish building acoustics regulations, DB-HR.

3.1 Legal/administrative/social challenges

When the GT1 started working on this standard it was agreed that the scope of the Spanish ACS would be to set the criteria and procedures in order to classify a building acoustically. It was also agreed to broaden the field of application in comparison to ISO ACS proposal, and to include most of the buildings considered in the DB-HR, so docent and sanitary spaces have been included.

One conflictive and difficult point for agreement has been if the standard should include requirements to the entities/individuals qualified to actually perform de classification (select verification procedure, perform sound insulation estimation, select the measurement samples, make the measurements…). The technical solvency of such individuals or entities must be strongly considered during the process although it is out of the scope of the standard and thus it was agreed to point it out in the standard, as detailed in section 3.2.5.

Once the ACS becomes a standard the real challenge will be to encourage and promote the use of it. That is, that the acoustic quality profile of new built and already existing buildings is declared and publicly available. In fact this is a quite complicated challenge since with the existing national building regulations, it is not possible to make an acoustic quality profile declaration mandatory. The declaration is in any case of a voluntary nature.

A possible way to promote the use of the ACS is to integrate the verification process described in it as a mandatory verification procedure in the corresponding building acoustics regulations DB-HR. This would have the following positive consequences:

- The acoustic performance of new constructed buildings would always be verified in situ. This would be extremely positive since the current DB-HR does not establish neither a verification process nor the obligation to carry out on-site verification measurements. The verification process is delegated to each of the 17 autonomous communities [21] and after 10 years of implementation, only 3 autonomous communities have established the obligation to carry out in situ verifications once the construction work is finished and few of them have defined the sampling process.
- The acoustic classification of the building would be declared voluntarily, since the data would already be available.

Concerning existing buildings, the application of the acoustic classification scheme needs to overcome the following obstacles:

- When performing the technical inspections of existing buildings [11], which are for many old buildings mandatory and serve to evaluate the building conditions, the performance of the acoustic evaluation is not obligatory. Including the acoustic performance of the building as mandatory in the periodic mandatory technical inspections would undoubtedly foster the use of the ACS also for existing buildings, since, as mentioned before, data would already be available.
- Another critical issue concerning the ACS of existing buildings is that in order to make measurements from an adjoining dwelling, it is necessary to have an authorization and this is not legally guaranteed. Without an authorization it can be very difficult to access a neighbouring space.
- Getting a low acoustic classification will very likely have a negative impact on the sale or rental prize. This can also be a handicap when trying to encourage owners to assess the acoustic quality of their properties.

3.2 Technical challenges

Most of the technical challenges found within the Spanish working group are an image of the challenges found within the ISO working group [20]. The good news is that within one same country, it is much easier to come to a compromise solution since the "boundary conditions" are the same.

3.2.1 Compatibility with existing DB HR: descriptors and limits

The descriptors used in the ISO draft were almost equivalent to the ones used in the aforementioned DB HR. The limits for each class were, however, so restrictive that in some cases, the Spanish existing requirement fell below class F in the ISO ACS proposal.

This can be observed in Table 1 which shows, as an example, the difference between the proposed ISO classification scheme and the adapted Spanish scheme for the impact sound insulation descriptor $L'_{nT,w}$. The Spanish DB HR limit in habitable rooms in dwellings from other dwellings and in all directions is $L'_{nT,w} \leq 65$. This would be below the worst class in the ISO proposal and thus could not be adopted in the Spanish ACS.

The experts in GT1 agreed from the beginning that the Spanish building sector and the society needed an ACS which could be used in Spain. Keeping the same limits as in the ISO proposal would produce a "useless" ACS for the Spanish building sector. Keeping this in mind, it was decided to adjust the limits so the requirements in the DB HR would correspond to class D, as it can be seen in Table 1.

Table 1. Comparison, for impact sound insulation, between proposed ISO ACS and Spanish draft ACS (PNE 74201)

	Type of space	**Class A**	**Class B**	**Class C**	**Class D**	**Class E**	**Class F**
ISO ACS proposal	In habitable rooms in dwellings from other dwellings in all directions	$L'_{nT,w} \leq 46$ and $L'_{nT,w,50} \leq 50$	$L'_{nT,w} \leq 50$ and $L'_{nT,w,50} \leq 54$	$L'_{nT,w} \leq 54$	$L'_{nT,w} \leq 58$	$L'_{nT,w} \leq 62$	$L'_{nT,w} \leq 66$
Spanish draft ACS		$L'_{nT,w} \leq 50$	$L'_{nT,w} \leq 55$	$L'_{nT,w} \leq 60$	$L'_{nT,w} \leq 65$	$L'_{nT,w} \leq 70$	$L'_{nT,w} > 70$

Another minor change was to include in the lower class F all the results worse than class E instead of setting a limit to class F as in the ISO proposal.

3.2.2 Assessment frequency range

The contribution of the low frequency noise (50 Hz; 63 Hz and 80 Hz third octave bands) to the perceived annoyance and to the subjective perception of sound insulation has long been debated [22–26].

When the DB HR was written, the subject of low frequencies was far from being a topic of interest and concern for the developers of the standard; on one hand because of lack of knowledge on the subject and on the other hand because at that time there were other priorities. The frequency range used for sound insulation assessment in the DB HR is 100-5000 Hz for airborne and façade and 100-3150 Hz for impact. This is not in full agreement with the ISO ACS proposal, neither in the low frequencies nor in the low frequencies, since in the ISO ACS proposal the assessment frequency range is 50-3150 Hz for higher classes and 100-3150 Hz for most classes, for airborne, impact and

façade sound insulation. For the sake of "usability and coherence" the Spanish ACS proposal, has been developed using the same frequency range as in the DB HR.

As of today, there is a strong interest on low frequencies sound insulation subject. Both researchers and administration bodies have become aware of the need to investigate about it. In fact, several critical points have already been detected and will have to be addressed in the coming years:

- In Spain there are no data about in situ sound insulation performance of typical constructive solutions taking into consideration the low frequencies.
- There is no knowledge on how including the low frequency performance should be transferred to a future revised regulatory document and how would it affect the building sector.
- The official data base with laboratory sound insulation data (Catálogo de Elementos Constructivos [27]) includes R_w, R_A, R_{Atr}, $L_{n,w}$, etc. calculated from measurements starting at 100 Hz; the same happens with data included in other existing catalogues.
- The in situ low frequency sound insulation measurements procedure for small rooms has not yet been adopted by most Spanish laboratories, since customers only request tests starting at 100Hz to verify compliance with the existing requirements.
- Concerning the upper frequency range limit, it has been observed that reducing it from 5000 Hz to 3150 Hz to converge with ISO ACS proposal would affect the corresponding sound insulation descriptors by ±1 dB. This needs also further study but, in principle, seems the easiest challenge to solve in a future revision of the Spanish DB HR and ACS.

For the future, the tendency should be to obtain the necessary knowledge in relation to insulation and low frequencies in order to extend the ACS to lower frequencies when relevant.

3.2.3 Façade limits

The way to express the limit for the protection against outdoor noise in the PNE 74201 is consistent with the ISO ACS proposal but adjusted to the existing requirements in the DB HR. In the ISO ACS proposal the requirement is related to L_{den} whereas in the PNE 74201 it is related to L_d. Table 2 shows an extract of ISO ACS proposal and PNE 74201. The DB HR requirement corresponds, in the PNE 74201, to class D when $L_d \leq$ 60 dBA. For $L_d >$ 60 dBA, the DB HR limit would fall in some cases into class E.

Table 2. Comparison, for façade sound insulation, between proposed ISO ACS and Spanish draft ACS (PNE 74201)

	Type of space	**Class A**	**Class B**	**Class C**	**Class D**	**Class E**	**Class F**
ISO ACS proposa $D_{nT,A,tr}$ l	Façades and roofs of habitable rooms; environment sound sources characterized by L_{den} / L_d	≥ L_{den}-20	≥ L_{den}-24	≥ L_{den}-28	≥ L_{den}-32	≥ L_{den}-36	≥ L_{den}-40
Spanish draft ACS $D_{2m,nT,Atr}$		≥ L_d-18	≥ L_d-22	≥ L_d-26	≥ L_d-30	≥ L_d-34	< L_d-34

Note: $D_{2m,nT,Atr}$ and $D_{nT,A,tr}$ are in fact the same descriptor with different notation.

3.2.4 Installations

Since the DB HR does not include any limit to installation noise (it includes recommendations for mounting and maximum sound power level), the main problem has been to avoid inconsistencies between admitted ISO measurement methods [28,29] and the Spanish development of the Noise Law [30]. Before making a decision regarding the definition of the requirements, as well as the test protocols to be followed in order to obtain the acoustic classification for installations, it was necessary to analyse both ISO standards and compare them with the Spanish law in order to find the common points and the differences between them.

Table 3 shows the most important points of the comparative analysis between the three documents.

Table 3. Comparison, for installations sound transmission, between ISO standards and Spanish noise law.

	ISO 16032	ISO 10052	Annex IV RD 1367/2007
Scope	Measurement of sound-pressure level produced by service equipment attached to or installed in buildings (sanitary installations, mechanical ventilation, heating and cooling service equipment, lifts, etc).	Measurements of airborne sound insulation between rooms; impact sound insulation of floors; airborne sound insulation of facades; and sound pressure levels in rooms caused by service equipment.	Measurement of airborne noise and structural noise transmitted by any sound source (machine, industry, installations, etc).
Accuracy	Engineering method	Survey Method	Not Specified.
Descriptors	L_{ASmax}; $L_{ASmax,nT}$; $L_{ASmax,n;}$ L_{AFmax}; $L_{AFmax,nT}$; $L_{AFmax,n;}$ L_{Aeq}; $L_{Aeq,n}$; $L_{Aeq,nT}$; L_{CSmax}; $L_{CSmax,nT}$; $L_{CSmax,n;}$ L_{CFmax}; $L_{CFmax,nT}$; $L_{CFmax,n;}$ L_{Ceq}; $L_{Ceq,n}$; $L_{Ceq,nT}$; Global results calculated from 1/1 octave spectrum. Levels corrected by Background noise.	For installations: L_{ASmax}; $L_{ASmax,nT}$; $L_{ASmax,n;}$ L_{AFmax}; $L_{AFmax,nT}$; $L_{AFmax,n;}$ L_{Aeq}; $L_{Aeq,n}$; $L_{Aeq,nT}$; L_{CSmax}; $L_{CSmax,nT}$; $L_{CSmax,n;}$ L_{CFmax}; $L_{CFmax,nT}$; $L_{CFmax,n;}$ L_{Ceq}; $L_{Ceq,n}$; $L_{Ceq,nT}$; Global results measured. No corrections by background noise.	$L_{keq,Ti}$ / $L_{keq,T}$ (Equivalent continuous sound pressure level, A weighted, corrected by background noise, and penalties applied of +0, +3, +6, or +9 dB for tonality, low frequency and impulsive components).
Spatial sampling	Three indoor measurements positions. One of them near the corner.	Two indoor measurements positions. One of them near the corner.	Three indoor measurement positions (for structural noise transmission), at least 1 m from the walls or any reflecting surfaces. If not possible, 1 position in the centre of the room.
Temporal sampling	Enough time to complete a work cycle defined of the installation.	Enough time to complete a work cycle defined of the installation.	At least for 5 seconds, during the noisiest work phase of the installation.

The conclusions of this study were that the method and the results obtained from the ISO Standards procedures are not comparable with the results obtained from the noise Spanish law. Thereby it was agreed to keep only ISO 16032 measurement method in order to assure the results repeatability, and accuracy, introducing the following explanatory note: "*the classification obtained does not imply compliance with RD 1367/2007 given that the test methodology is different*."

On the other hand, another problem that the working group found for installations noise classification was the impossibility to measure in many cases the individual installations (mainly cooling and heating installations) before the dwelling occupation. Due to this, a decision was made to add a note with the following text: "*In the cases where it is not possible to evaluate individual heating/cooling installations during measurements campaigns for building classification, it must be indicated in the building certificate report that the mentioned installations are out of the scope of the classification report*."

3.2.5 Verification procedure

The ISO ACS proposal provides some guidelines for verification of classes and refers to the corresponding measurement standards but leaves many options/choices open. This could eventually result in two different classifications of a same building depending on the sampling. Besides, it is also quite open concerning who can be appointed to select the sampling spaces or make the measurements.

In fact this has been the most troublesome point to discuss within the GT1. If one aims at providing guidelines to do the best possible sampling both from a statistical point of view and from an acoustical point of view, the guidelines would become the "heart" of the standard and the applicability of the standard would be much reduced. In the draft Spanish ACS additional guidelines have been included, so that even if two different consultants were to make a sampling plan or strategy, the resulting classification would, in most cases, be the same.

The guidelines suggest a prioritization process depending on different factors. A summary of the guidelines is included hereinafter:

Step 1: Selection of the verification procedure:

Procedure A: Defined in three stages:

- Design and calculation stage according to ISO 12354. A preliminary sampling plan is designed and sensitive rooms are identified;
- Construction stage. Visual inspections are carried out to verify that elements' installation is made according to the project's specifications;
- Field measurements stage.

Procedure B: Verification by field measurements only.

Step 2: Identification of cases:

- Identification of all protected rooms;
- Identification of cases for each identified protected room;
  Cases are related to the acoustic characteristics: airborne sound insulation, impact sound pressure level, noise from service equipment, reverberation time, etc.
- Identification of construction systems for each identified case (subcases)

Step 3: Quantification of sampling

- 5% of the subcases in Procedure A and 10% of the subcases in Procedure B;
- It's indispensable that all activities/equipment premises are tested in at least one case for sound insulation;
- Concerning the noise transmitted by service equipment, for each installation, at least one test will be carried out, selecting the worst possible working case.

Step 4: Criteria for the selection of the rooms to be tested

- Use and type of rooms as well as its adjoining;
- General criteria (Expansion joint, coatings, ground floors, higher value of L_d,…)
- Geometric criteria (Volume/surface ratio, windows ratio, …).

Step 5: Additional criteria for facilities noise and reverberation time.

It was not easy to come to an agreement concerning who is qualified to estimate the performance of a construction, to identify rooms or constructions which can be sensitive at the design stage, to propose the sampling strategy or to make the sound insulation measurements. The compromise solution was the following text: "*The persons or organizations designated to perform the theoretical calculations and / or visual inspections must be able to demonstrate that they are qualified for these tasks. The entities designated to carry out the relevant acoustic tests must be competent and comply with the requirements of UNE-EN ISO / IEC 17025 with regard to the applied measurement standards.*"

In relation to the criteria for assigning classes and following the philosophy of the ISO ACS proposal, it was agreed to avoid referring to the measurements' uncertainty and rather allow a 2 dB tolerance for individual results provided that, for each criteria, the arithmetic average of the results without considering the measurement uncertainty (when reported) complies with the corresponding class limit.

Finally, the Spanish ACS will incorporate as an annex a suggested report template detailing the minimum contents that must be included when delivering a classification report.

5. EXPECTED IMPACT ON SOCIETY

The development of initiatives that improve the quality of life of citizens is a challenge of modern societies. In this sense, different sectors of society have demanded and are expecting with great interest, the development of a regulation/tool enabling the acoustic classification of buildings according to the Spanish existing sound insulation requirements.

Some of the sectors of society on which this regulation is expected to have a relevant impact are the following:

- Housing promoters: Having the possibility to provide residential spaces with an acoustic performance tag (classification) will undoubtedly make it easier for promoters who chose to invest in better acoustic performance than required, to sell their product and obtain an economical benefit from the investment. Nowadays more and more citizens are aware of the importance of having high protection against noise and are willing to pay a little more in exchange for it [31].
- Building rehabilitation sector: The application of this regulation will allow comparing the acoustic performance of a dwelling/building prior to and after rehabilitation. This will encourage taking into account the acoustic improvement of the building when projecting and performing a rehabilitation project. Besides, it can become also a useful tool for the administration when funding rehabilitation of the old building stock.

- Manufacturers of acoustic and building materials: This classification system will encourage the manufacturers to invest in the development of new acoustic products and new constructive systems with better acoustic performance.
- Engineers and professionals of the acoustic sector: From this sector, the development of the ACS is seen with interest since its correct implementation needs to be carried out by technicians with specialization and experience in the field of acoustics.
- Citizens who seek acoustic comfort in their homes or places of rest (for example hotels): The regulations will allow citizens aware of acoustic comfort to have more information when making decisions about which house to buy or where to stay.

6.- CONCLUSIONS

Acoustic classification schemes are a powerful tool for encouraging the building sector to improve the acoustic quality of buildings. The Spanish standardisation working group GT1, upon request, has developed an ACS based on the ISO ACS proposal. It has been necessary to study and analyse the divergence points between the existing legislation in Spain and the ISO proposal. After this study, the PNE 74201 has been developed, and is expected to be become a Spanish standard before the end 2019.

During the development process the GT1 agreed that the Spanish ACS had to be coherent with the existing Building Code and protection against noise regulations (DB HR). Sound insulation descriptors and assessment frequency ranges were selected to meet the existing Spanish requirements and thus facilitate the acceptance, recognition and implementation of the ACS by the administrations, promoters and final users.

The experience gained over the last decade allows making the following recommendations:

- For the Spanish building sector: Since there is a growing interest in adequately evaluating the effect of low frequency noise both in sound insulation assessment and users perception of sound insulation, it is recommended to slowly start gaining expertise in sound insulation measurements at low frequency. In the mid/long term, when the building acoustics requirements will be updated, it would be convenient to have the market ready for the inclusion of the three lower third octave bands in sound insulation assessment when necessary. It is also important to gain knowledge on the effect of the low frequency performance of typical constructive solutions on the corresponding sound insulation descriptors. Only by having this knowledge it will be possible to undertake an adequate revision of building acoustics regulations.

- For countries already having an ACS: Each existing ACS is undoubtedly the result of research, discussions and agreements within each country and is coherent with the corresponding building acoustics regulations. Nevertheless it is recommended to keep in mind that, at least within the EU, the best future scenario is a harmonized building acoustic language. In spite of the big differences in construction and cultures, the scientists and legislators are responsible of providing a universal language and tool for constructors, architects and citizens in the EU. Agreeing on a language does not imply agreeing on the level for the requirements.

- For countries not having an ACS: It is advised to develop their corresponding ACS in line with the ISO proposal. By doing this on one hand they will build on the knowledge acquired by others who have already compared and studied many existing ACS and on the other hand they will facilitate the reciprocal understanding of building acoustic regulations.

A European Directive about building acoustics would be of great help to encourage the different member states to continue working and making efforts to gradually merge their respective building acoustic regulations and introducing harmonized sound insulation descriptors, frequency ranges and acoustic classification schemes.

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