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On the acoustical retrofit of existing buildings: comparative study of regulations in Europe and other countries

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ABSTRACT

Over the last recent years, an increase in people's awareness has arose about the benefits effects of the indoor environment on human comfort and health conditions. In terms of acoustics, noise reduction and sound transmission control has become a significant issue to be taken into account, since domestic complaints about noise have increased five-fold in some countries. Overall, it is estimated that in the last two decades only 15% of the housing stock will be at least at the level of the current standards demand for new dwellings, so that attention thus be focussed on existing buildings, as they provide more possibilities to be renovated. In this regard, it is interesting to note that not all national Building Codes and Standards take into account the regulation of old buildings, precisely when most of the housing stock was built at a time with lack of regulatory policies. The aim of this paper is thus to develop a comparative study of the acoustic requirements established in current building regulations around the world, mainly focused on the acoustical retrofit of existing buildings. The analysis aims to solve some doubts that arise in this field.

Keywords: acoustic regulations, existing buildings, acoustical retrofit, refurbishment, rehabilitation
I-INCE Classification of Subject Number: 80
http://i-ince.org/files/data/classification.pdf

1. INTRODUCTION

In most countries, more than 50% of housing stock was built prior to sound insulation codes had been introduced, and, in relation to this issue, the current legal requirements have not significantly changed in the last twenty years. In this regard, having had insufficient attention throughout time, the aging of the housing stock around

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the world has become one of the main concerns to the scientific community due to the deficiencies shown in relation to the compliance with regulatory standards. The construction systems used in the past are far from reaching the minimum conditions established for new buildings, and therefore to achieve adequate comfort conditions.

In terms of acoustics, the increasing demand for sound insulation is justified by the negative effects of noise [1]. In addition, experts' concerns about this issue has promoted the analysis of regulations requirements and guidelines [2], in order to achieve the maximum degree of well-being for the occupants of dwellings and to obtain better levels of acoustic comfort.

In pursuit of an harmonized set of descriptors and classification scheme, an international standard is under development by ISO TC43/SC2/WG29 based on the outcomes of the COST Action TU0901 [3], an intergovernmental framework aimed at facilitating the collaboration of European scientific community. Before this European project, Rasmussen develop a research to analyse present national schemes in Europe focusing on comparing the range of quality levels, number of quality classes and class intervals [4]. Reference should also be made to other studies that focuses on requirements and on descriptors, including suitability considerations [5,6], such as the study developed by Del Val, L. et al., a work whose main goal was to provide, based on a statistical analysis, a translation equation for each relation between existing-proposed sound insulation descriptors [7].

The main objective of this work is to develop a comparative study between the acoustic national requirements of dwellings determined in current Building Codes (BC) existing around the world, but mainly focused on the acoustical retrofit of existing buildings. This documentary work has been analysed by other researchers and for other type of buildings, such as Machimbarrena and Rasmussen that established a comparison for housing and school between regulations of European countries and South America [8].

This analysis also aims to solve some doubts that arise in terms of acoustic retrofit such as: Which are the perspectives in terms of acoustic regulations? Are there numerical requirements for existing buildings? Which are the verification methods when assessing sound transmission/insulation? Do the building codes and standards provide constructive systems and solutions than comply with requirements? These are some of the questions this paper tries to focus on.

2. ACOUSTIC RETROFIT

One of the main issues is that construction activities have mainly oriented to new buildings rather than work on existing buildings and facilities. Fortunately, the concept of acoustic renovation of the housing stock is at last gathering pace, since the need for defining methodologies to renovate while maintaining a comfortable and healthy indoor environment is building up a significant scenario.

The project of rehabilitation of a building is mainly aimed at energy-saving interventions, even though sometimes taking into account the importance of acoustic comfort and therefore the reduction of noise. Rasmussen reflects on this topic, wondering why is sound insulation between dwellings in renovated housing not upgraded like other qualities, hoping that joint efforts could lead to more focus on the issue [9]. In fact, in relation to the renovation of existing stock, the building codes of some countries propose strategies and interventions from the structural, energy and fire protection point of view, being acoustic retrofit sometimes not considered.

2.1 Sound insulation and sound transmission in existing buildings

Sound or noise may be caused by a series of random and uncontrollable events, and levels and types of noise found within dwellings have increased, leading to frustration and stress for occupants. Neighbour noise is now a significant problem, which has been omitted for decades, both for existing housing and new housing. In fact, in the last 15 years, domestic complaints about noise have increased five-fold.

According to this and based on the importance of ensuring acoustic comfort and the improvement of life quality also in existing housing stock, sound insulation and noise reduction have had to be included by architects and engineers in their designs for buildings and specifically for dwellings. However, when assessing historical building acoustical retrofit, a new difficulty also arises, since the proposed upgrade interventions are part of a conservation plan that should protect heritage. In this regard, interventions must be coherent and respectful with the historical significance of the building, being essential to avoid the destruction of important historical elements in order to fulfil contemporary acoustical requirements. Therefore, technicians must achieve the optimum level of sound insulation by enhancing traditional constructive solutions that could be adapted to current paradigms [10].

2.2 Aging of worldwide housing stock

One important aspect to be considered is the period of construction of dwellings, since data on the age of the housing stock is a reliable reference about their physical characteristics and the construction conditions.

In most European countries, a large amount of buildings are relatively old, since almost a half of the residential stock was built before 1970 [11]. A singular fact is that buildings were generally poorly insulated in this period because of the limitation or the lack of standards. In northern Europe the average of dwellings built in post-war period is 29%, being in some cases, such as Sweden, almost 38% [12]. The situation is not very different when it refers to southern Europe because the amount of ancient housing stock is also considerable. Some studies established a range between 63% and 76% of the total housing stock were built before 1980 [13], being 46% of residential Spanish buildings built after the II WW. In the case of Portugal, it is determined that around 34% of the buildings need some type of intervention to fulfil the current comfort requirements [14].

In USA, according to National statistical data, the average age of owner-occupied homes is 37 years and, although the age is not as high as in European countries, more than a third of the current housing stock was built before 1970 [15]. Approximately, a 30% of Australian dwellings were built more than 50 years ago, and ‘multi-unit’ dwellings are now a significant part of the new home building stock [16]. In Japan the percentage of old housing built before 70’s is about a 40% of the current stock. However, it should be taken into account that housing density is drastically higher [17]. The housing stock in the Russian Federation is young compared to that in Western Europe. However, although urban housing stock is fairly new, technically the houses are not in a good condition due to its low-quality construction and poor maintenance [18].

3. COMPARATIVE BETWEEN ACOUSTIC NATIONAL REQUIREMENTS

It is assumed that the retrofit interventions carried out in different countries worldwide will not be applied in the same way due to the variability of climatic environments, the urban density, the aging of housing stock, the variety of constructive solutions and characteristics of the buildings, among other factors. Although it can be conceived as a simple reference to the acoustic aspect, different tendencies are observed in terms of facing the problem of noise. In this regard, when analysing the different national regulations, legal requirements and the BC of different countries, the diverse terminology used in terms of acoustic comfort is relevant: sound insulation, sound transmission, protection against noise or noise reduction are some of the terms used in these documents. However, the main aspect analysed in this work and to which the main attention is paid, is a comparative study between the different acoustic requirements around the world, focusing it on the acoustic retrofit of existing buildings.

3.1 Comparison between insulation indexes used in regulations

It is of great interest to note the main requirements established by countries are defined by different insulation indexes, that is to say the in situ regulatory index $D_{nT,w}$ or the laboratory index R_w. As already known, it is necessary to apply a conversion to the R_w parameter to obtain the D_{nTw} regulatory index. Moreover, research studies confirm the different evolution of both indexes, since an increase in R_w does not mean an increase in the same proportion of the $D_{nT,w}$. This behaviour is due to the indirect transmissions that occur in reality, which in laboratory tests are not observed.

On-site sound testing of internal walls and intermediate floors cannot be relied upon due to excessive flanking sound transmission. In this regard, one of the key issues in acoustic retrofit is try to find out the acoustic insulation index measured in the laboratory (R_w), which in turn is a consequence of the successive R'_w of the indirect transmissions exerted by all the constructive elements involved in the transmission of noise. Assuming that we have a building with homogenous historical solutions which are normally heavyweight, it is possible to obtain the value of the acoustic reduction index based on the mass law. But what is no longer so easy to apply the calculation methods proposed the Building Codes to find out the reduction rates of the lateral transmissions, confirming that it is an almost impossible procedure [19]. Figure 1 shows a proposed sequence of recommended procedures to follow in rehabilitation interventions [20].

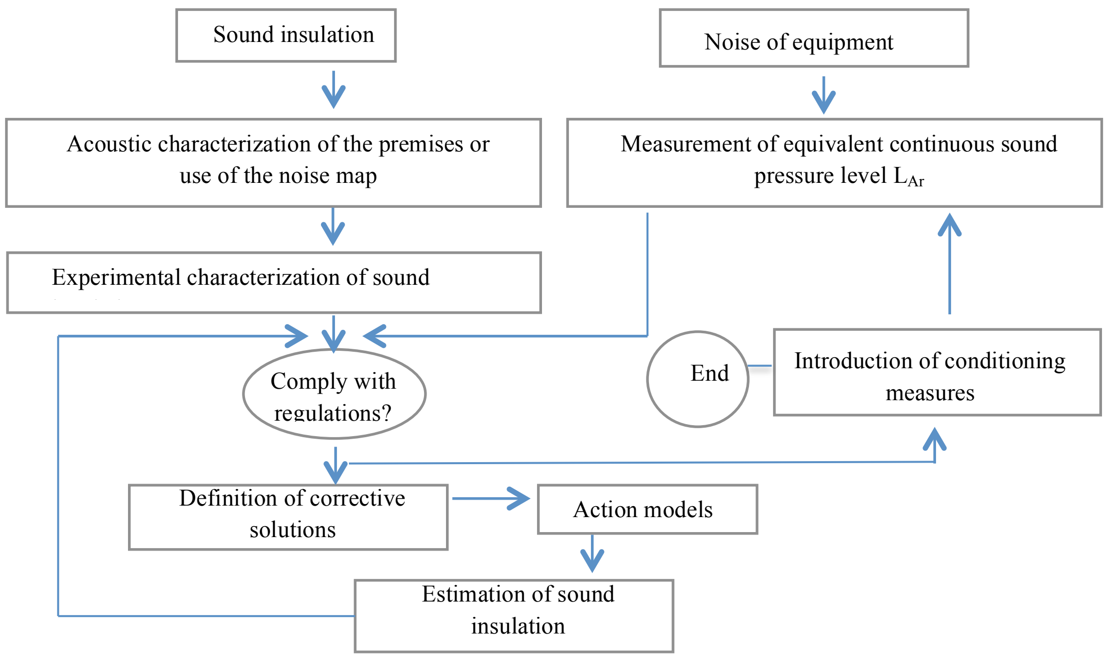

Figure 1. Sequence of recommended procedures to follow in rehabilitation interventions [20].

The spectrum adaptation terms C (pink noise) and C_{tr} (road traffic noise) have been included to take into account the different spectra of noise sources for airborne sound insulation. In the case of C_{tr}, this term is included by some national standards when a representative urban traffic noise is assumed as the loading noise, confirming there are significant differences in the descriptors and levels of each country.

For this reason, it will be important to determine if the acoustic insulation index should be the same as that considered in the evaluation of new buildings or if, by contrast, the verification procedure should be different in the case of old buildings.

3.2 Comparison between acoustic considerations for existing buildings

It should be noted that there is a general lack of regulatory policies and not all the countries analysed in this study have specific considerations of sound insulation in existing buildings, only few of them attend to noise requirements or a determination of quality classes intended for renovated housing. That is why it is difficult to find an extensive list of management and strategies for rehabilitation in residential sector, that often undergo alterations such as change of use, extension, partial demolition, retrofitting, or just maintenance, in order to modify or improve their acoustic performance. Nonetheless, towards achieving this common goal, various actions and standards have been implemented in different countries to regulate refurbishment procedures. As other comparative studies in Europe, this work also shows a high diversity of considerations, descriptors and limit values for fulfilling acoustic requirements in the old stock.

In Spain there is specific criteria for works in existing buildings, although there are no specific regulations and the compliance requirements of the Building Code (BC) does not apply when it refers to works of extension, conversion or reform in existing buildings, except in the case of integral rehabilitation. In this case, historic buildings are exempt when adaptation works are technically unfeasible. For these interventions, the designer or the project manager can adopt alternative solutions, provided it is justified that the projected building meets the basic requirements because its benefits are, at least, equivalent to those that would be obtained by the application of the BC [21]. It should also be noted the recent establishment of Acoustics of the Existing Building Evaluation Report, which assess the acoustic performance of a building, among other aspects, although it does not regulate it.

In other European countries such as the United Kingdom, the considerations are differentiated according to the nation to which it refers. In England and Wales the document E - Resistance to the passage of sound is applicable [22]. In relation to existing construction, the material change of use is the basic consideration, understood as a change in the purposes for which or the circumstances in which a building is used. The Document exposes required values in dwellings for walls, floors and stairs that have a separation function (Table 1). In order to achieve these requirements and before a wall or floor treatment is applied, appropriate remedial work to the existing construction should be undertaken. In Scotland, it is established that in the case of conversions, the building shall meet the standard requirements. In this country there is a very complete bibliography regarding the conservation of buildings and some useful documents in terms of rehabilitation are published: a guide for practitioners focused on conversions of traditional buildings [23]; or a book that provides improving existing attached dwellings and designing for conversions [24]. However, as with other countries, there are no mandatory requirements, but procedures may serve as a helpful guide to reduce noise transmission, or key stages as actions for evaluating and improving sound insulation.

In Ireland, in the case of material alterations or changes of use of existing buildings, the adoption of the guidance in the BC without modification may not be appropriate. Alternative approaches based on the principles contained in regulations may be more relevant and should be considered [25]. In Portugal, the regulation of acoustic requirements of buildings (RRAE) determines acoustic requirements according to the type of building. These limit values are not only directed to the new construction, but also to old buildings that are subject to reconstruction or alteration processes [26].

One of the sections of the acoustic regulation of buildings in France is focused on the considerations relating to existing buildings. It presents a historical evolution of acoustic requirements, a comparison of limit values, and determines the acoustic characteristics of existing buildings and when they should be considered. In the case of residential buildings prior 1970, the alterations of any housing equipment must comply with the provisions of current regulations and the development work should not have the effect of reducing the acoustic insulation characteristics of the home. Some tables in Appendix 1 of the code define the values of the acoustic requirements that refer to the façade or ceiling elements directly affected by the global energy-saving works and the important renovation works mentioned in BC [27]. These requirements are assessed according to the location, the ratio of the surface area of the elements in relation to the surface of the ground or the relationship between the surface of the roof and the surface of the ground, and the number of entries of air in the room under study.

Other European countries, mainly Nordic, such as Denmark, Finland, Norway, Sweden, Iceland, Netherlands, Lithuania, and also Italy, have introduced sound classification schemes in order to determine different levels of comfort in terms of acoustics. Among the different class denotations, in most cases the relation to each national BC is indicated, together with the required classes intended for new dwellings (generally C or III) and also for renovated housing (generally D or IV) as is the case of the least restrictive. In relation to classification schemes, in Portugal, a method for rehabilitated housing buildings is under development. The proposed methodology has three classes reserved for the new buildings, which must comply with current legal requirements, and other five classes for old housing. The different class denotations will allow users to decide the best remedial solutions based on the acoustic classification [4].

Regarding other countries, in the case of USA, a detailed Building Code whose requirements focused on existing buildings is intended to provide requirements for repair and alternative approaches for alterations and additions. However, no section does refer to acoustic requirements [28]. The National Construction Code of Australia exposes the performance requirements, verification methods and determination of sound insulation ratings [29]. Although there are no specific requirements for existing buildings, the handbook of sound transmission and insulation in buildings, a non-mandatory document, presents procedures to be followed during refurbishment treatments, since great care must be exercised during the building renovation process to ensure that the new building work complies with the current BC [30]. To this end, diverse areas are established on requiring extra attention, as is the case of wall constructions and limiting flanking paths, treatments applied to seal gaps or the control of noise and vibration travelling through timber floorboards, joists, beams, external walls or ceilings.

Table 2 summarizes relevant data considering the sound insulation requirements found in the current building acoustic regulations in the selected European countries. Table 3 summarizes relevant data considering the sound insulation requirements found in the current building acoustic regulations in other selected countries worldwide. It should be noticed that due to the difficulty of interpreting certain regulations by language, the existence of requirements in old buildings should be further analysed.

Table 2. Relevant data considering the sound insulation requirements of European countries and the corresponding class

EUROPE					
Country	**New buildings**		**Existing buildings**		**BC or Standard**
	Airb. Sound	**Imp. sound**	**Airb. sound**	**Imp. sound**	
AT	$D_{nTw} > 50/55$	$L_{nT,w} \leq 48$			OIB-330.5-002/15
BE	$D_{nTw} > 54$	$L_{nT,w} \leq 58$			NBN S01-400-1
DK	$R'_w \geq 55$ (C)	$L'_{n,w} \leq 53$ (C)	$R'_w \geq 50$ (D)	$L'_{n,w} \leq 58$ (D)	DS 490, [30]
EN&WA	$D_{nT,w} + C_{tr} \geq 45$	$L'_{nT,w} \leq 62$	$D_{nT,w}+C_{tr} \geq 43$*	$L'_{nT,w} \leq 64$*	Building Regulations – Document E
FI	$R'_w \geq 55$ (C)	$L'_{n,w} \leq 53$ (C)	$R'_w \geq 49$ (D)	$L'_{n,w} \leq 63$ (D)	SFS 5907
FR	$D_{nT,w} + C \geq 53$	$L'_{nT,w} \leq 58$	According zones of *Plan de Gêne Sonore* (PGS) [25]		Réglementations acoustiques bâtiments
DE – Multi	$R'_w \geq 53$ (I)	$L'_{n,w} \leq 53$ (I)			DIN 4109
DE – Row	$R'_w \geq 57$ (I)	$L'_{n,w} \leq 58$ (I)			
GR	$D_{nTw} > 53$ Κατηγορίας 3	$L'_{nT,w} \leq 57$ Κατηγορίας 3	$D_{nTw} > 50$ Κατηγορίας 4	$L'_{nT,w} \leq 64$ Κατηγορίας 4	λληνικό Κανονισμό Κτιριακής (Greek Building Regulation)
IS	$R'_w \geq 55$ (C)	$L'_{n,w} \leq 53$ (C)	$R'_w \geq 50$ (D)	$L'_{n,w} \leq 58$ (D)	Byggingarreglugerð (Building regulations)
IR	$D_{nT,w} \geq 53$	$L'_{nT,w} \leq 58$			EN ISO 16283-1 EN ISO 140-7
IT	$R'_w \geq 50$ (III)	$L'_{n,w} \leq 63$ (III)	$R'_w \geq 45$ (IV)	$L'_{n,w} \leq 68$ (IV)	UNI EN ISO 11367
LT	$D_{nT,w}$ / $R'_w \geq 55$	$L'_{n,w} \leq 53$	$D_{nT,w}$ / $R'_w \geq 52$	$L'_{n,w} \leq 58$	STR 2.01.07
NL	$D_{nTA} > 52$ l_{luk}*** > 0 dB	$L_{n,T,A} < 53$ l_{ico}** > 5 dB	$D_{nTA} > 47$ (IV)	$L_{n,T,A} < 58$ (IV)	NEN 5077
NO	$R'_w \geq 55$ (C)	$L'_{n,w} \leq 53$ (C)	$R'_w \geq 50$ (D)	$L'_{n,w} \leq 58$ (D)	NS 8175
PT	$D_{nT,w} \geq 50$	$L'_{nT,w} \leq 60$			RRAE
SC	$D_{nT,w} \geq 56$	$L'_{nT,w} \leq 56$			Technical Handbook
ES	$D_{nT,w} + C \geq 50$	$L'_{nT,w} \leq 65$			DB-HR
CH	$D_{nT,w} + C$	$L'_{nT,w} + C_I$			SIA 181

Class denotations in parenthesis Y= Yes;
* Material change of use / ** plane $l_{co} + L_{nTw} \approx 75$ dB - descendent $l_{co} + L_{nTw} \approx 65$ dB / ***$D_{nTw} = l_{luk} + 55$ dB

Table 3. Relevant data considering the sound insulation requirements of worldwide countries and the corresponding class

WORLDWIDE			
Country	**New buildings**		**BC or Standard**
	Airborne sound	**Impact sound**	
USA	$STC \geq 50$ $D_{nT,w} \geq 45$	IIC 50 $L_{n,w} \leq 60$ / $L'_{nT,w} \leq 65$	ASTM E90-09 ASTM E492-09
JP	D-45	L-55	JIS 1418
AU	$R_w + C_{tr} \geq 50$ $D_{nT,w}+C_{tr} \geq 45$	$L_{n,w}+C_I \leq 62$ (f) $L'_{nT,w} \leq 62$ (w)	NCC
RU	$R_w \geq 52$	$L_{n,w} \leq 60$	СП 51.13330
CA	$ASTC \geq 47$ $STC \geq 55$	$FIIC \geq 50$ $IIC \geq 50$	
CH	R_A / $R'_A \geq 45$	$L'_{nT,w} \leq 75$	Manual Reglamentación Acústica O.G.U.C.
BR	$D_{nT,w} \geq 45$	$L'_{nT,w} \leq 80$	NBR 15575-3

f: floor, w: wall

Most of the population in South America is concentrated in Argentina, Chile and Brazil. In Argentina there are recommended acoustic insulation values, but they are not mandatory. In Chile and Brazil there is an acoustic regulation of insulation requirements [31,32], however, the provided values can be considered lax compared to other countries. There is no reference to acoustic requirements for existing buildings.

Other countries also do not mention existing buildings, or it is not already specified if the indicated requirements also refer to existing buildings. There are cases in which even no distinction is made within the same category, including buildings located in quiet areas and noisy areas, the first limits being too restrictive, and the last ones insufficient.

Figure 2 shows the required values of airborne and impact sound insulation, determined in national standards and BC for new residential buildings and renovated residential buildings. In general, the values required for old buildings vary between 3-6 dB with respect to the requirements in new buildings. The analysis of the figure reflects the disparity of requirements between countries, since the requirements for old buildings are, in some cases, equal or even more stringent than for new buildings. As mentioned above, there are numerous aspects that may influence the determination of limit values. The climate, the age of the building and the constructive characteristics of the country are clear influential factors. However, this variability should not be so significant.

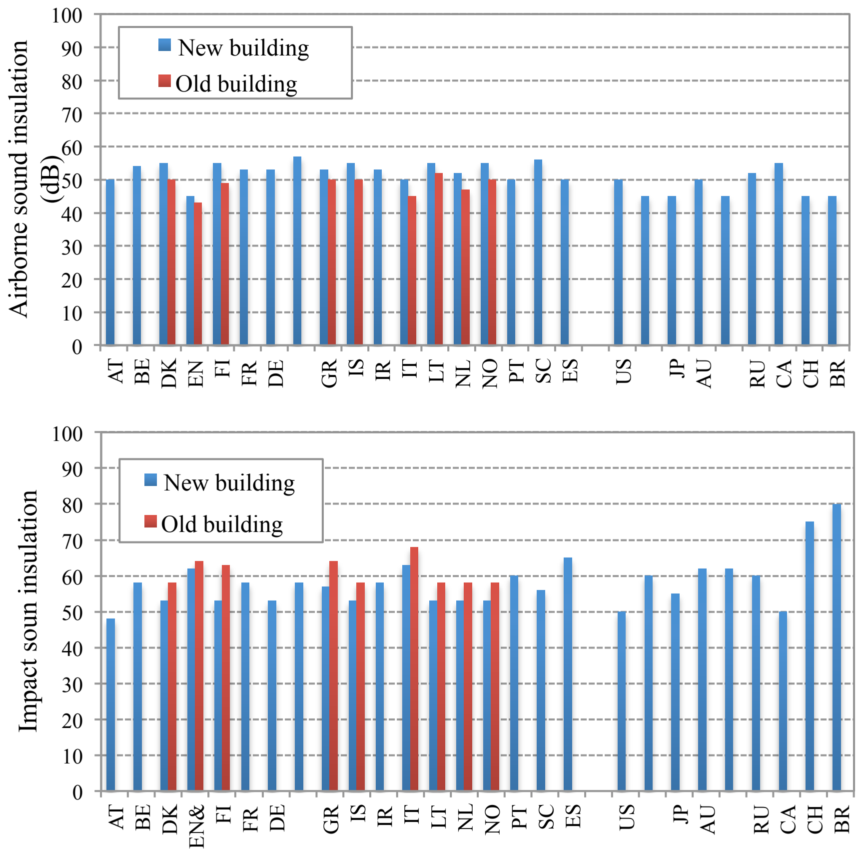

Figure 2. Required values set in national standards and BC for new residential buildings and renovated buildings: a) Airborne sound insulation, b) Impact sound insulation

4. CONCLUSIONS AND FURTHER DEVELOPMENTS

The analysis of the aging of housing stock states there is a need for renovation because at the time of construction regulations were very limited or even non-existing in terms of comfort. Considering noise as a health issue, acoustic comfort improvement has become one of the most important variables to be taken into consideration during building design and construction process.

In this paper a comparative study is developed on the acoustic requirements established in current building regulations around the world, mainly focused on the acoustical retrofit of existing buildings. This analysis allowed to determine which are the perspectives in terms of national acoustic regulations and national Building Codes. Not all countries consider acoustic retrofit in order to enhance sound transmission in old buildings, and numerical requirements are only defined in few national standards. However, technical documents are provided by some countries as help books for the technicians, with constructive systems and solutions than comply with requirements. To this end, this paper provides the basis for discussing future cooperation on optimizing acoustic regulations for existing buildings.

Further developments will be focused on the need to develop good management strategies for rehabilitation of housing buildings, which should be applied to achieve a more extensive sustainable residential stock. The basic motivation of these initiatives should be understood as an idea that every renovation work, independently of its extent, could be considered as an opportunity to enhance the acoustic performance of existing buildings. It will be also important to promote tasks and tools for upgrading sound insulation requirements and to make an efficient and effective implementation of databases and guidelines for improvement of existing housing.

5. ACKNOWLEDGEMENTS

The authors hope that data from national Building Codes and regulations have been correctly interpreted. Any corrections or updates of data will be appreciated.

6. REFERENCES

1. M. Basner et al. "*Auditory and non-auditory effects of noise on health"*. Lancet 383, pp.1325–32 (2014).

2. U. Berardi: "*Sound classification of dwellings - a comparison between national schemes in Europe and United States"*. J Acoust Soc Am 135(4) 2379 (2014).

3. COST Action TU0901 *"Towards a common frame work in building acoustics throughout Europe"* (2013).

4. B. Rasmussen, *"Sound classification of dwellings – Quality class ranges and intervals in national schemes in Europe*". Proceedings of Euronoise 2012. Prague, Czech Republic

5. B. Ramunssen. *"Sound insulation between dwellings – requirements in building regulations in Europe"*. Applied Acoustics 71, pp. 373-385 (2010).

6. B. Ramunssen. *"Sound insulation between dwellings – descriptors applied in building regulations in Europe"*. Applied Acoustics 71, pp.171-180 (2010).

7. L. Del Val, M. Machimbarrena, M. Herráez, C. Monteiro, R. Johansson. "*Translation between existing and proposed harmonized impact sound insulation descriptors and alignment within a proposed common acoustic classification scheme for buildings*". Applied Acoustics 129, pp. 204-2016 (2018).

8. M. Machimbarrena, B. Rasmussen. *"Comparison of acoustic regulations for housing and schools in selected countries in Europe and South America – A pilot study"*. Proceedings of the 22nd ICA. Buenos Aires, Argentina, (2016).

9. B. Rasmussen. *"Why is sound insulation between dwellings in renovated housing not upgraded like other qualities?"* Proceedings of EuroRegio, Porto, Portugal, (2016).

10. D. Queirós, R. Calejo Rodrigues, N. Pereira. *"Historical building acoustical retrofit: an experimental examination of traditional wooden floors"*. Build Acoust 23(3) pp.181-91 (2016).

11. S. Roberts *"Altering existing buildings in the UK*" Energy Policy 36(12), pp. 4482e6 (2008).

12. L. Itard, F. Meijer. "*Towards a sustainable Northern European housing stock*", Sustainable Urban Areas, 22, TU Delft, Amsterdam: IOS Press (2008).
13. I. Theodoridou, A.M. Papadopoulos, M. Hegger, *"A typological classification of the Greek residential building stock"*, Energy Build. 43, pp.2779–2787, (2011).
14. S. A. Magalhaes, V.P.de Freitas. "*A complementary approach for energy efficiency and comfort evaluation of renovated dwellings in Southern Europe".* Energy Procedia 132, pp, 909-14 (2017).
15. American Community Survey (ACS). National Association of Home Builders (2016).
16. Census of Population and Housing: Australia, Australian Bureau of Statistics (2016).
17. Statistics Bureau of Japan, Ministry of Internal Affairs and Communications.
18. United Nations "*Country Profiles on the Housing Sector:Russian Federation"* Geneva, (2004).
19. Consejo Superior de los Colegios de Arquitectos de España. *"El Nuevo codigo técnico de la edificación y la restauración arquitectónica".* Barcelona, Spain, (2006).
20. J. Patricio. "A acústica na reabilitaçao de edifícios. 4th Ed. Ed. By Quantica Editora. Engebook, Porto (2018).
21. T. Carrascal García, A. Romero Fernández, B. Casla Herguedas. "*Noise requirements in existing buildings in Spain: New proposals and the Existing Building Evaluation Report*" Proceedings of Euronoise, Maastricht (Germany) (2015).
22. H M Government. *"Resistance to the passage of sound-Document E*" The Building Regulations (2015).
23. D. Urquhart. "*Conversion of Traditional Buildings. Application of the Scottish Building Standards. Part 1"*. Edited by D. Urquhart. Historic Scotland, Edinburgh (2007).
24. S. Mith, J.B. Wood and R. Mackenzie. "Housing and Sound insulation - Improving existing attached dwellings and designing for conversions". Edinburgh (2006).
25. Building Regulations 2014. "*Technical Guidance Document E – Sound*" Ireland (2014).
26. Regulamento dos Requisitos Acústicos dos Edifícios, Decreto-lei 96/2008. Portugal.
27. Code de la construction et de l'habitation. "*Section 5-Sous-section 2: Caractéristiques acoustiques des bâtiments existants*" Republique Française (2018).
28. International Code Council Series. "*International Existing Building Code*" (2018).
29. National Construction Code Australia. Part F5 – Sound Transmission and Insulation (2016).
30. Sound transmission and insulation in buildings. Australian Building Codes Board (2018).
31. ABNT NBR 15575-3. Edificaçoes habitacionais – Desempenho. Parte 3: Requisitos para os sistemas de pisos.
32. Manual de Aplicación Reglamentación Acústica. Ordenanza General de Urbanismo y Construcciones. Gobierno de Chile, Ministerio de Vivienda y Irbanismo (MINVU).