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Building acoustic regulations in Europe – Brief history and actual situation

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Acoustic regulations for housing, educational buildings and some other building categories now exist in most countries in Europe, but findings from comparative studies show that extent and strictness as well as descriptors vary considerably across Europe. The acoustic performance areas dealt with are e.g. airborne and impact sound insulation, reverberation time, traffic noise, service equipment noise. Comparing countries, there is in general no consistency of contents, structure or enforcement of acoustic regulations.

Building acoustic regulations are typically valid for new buildings only, including buildings converted to other uses, but most often not for renovated buildings, if uses are unchanged. Consequently, large parts of the building stock constructed in periods with missing or weak acoustic regulations still suffer from poor acoustic quality, in spite of other qualities being upgraded. In most countries, the first acoustic regulations were for housing, in some countries in the 1950'es or earlier, and the next acoustic regulations were made stepwise for e.g. educational buildings, kindergarten, hospitals etc.

The paper includes examples from comparative studies of the current regulatory acoustic requirements in Europe, thus illustrating the diversity in the actual situation. The examples will include cases from the Nordic countries and encourage more harmonization of acoustic regulations in the Nordic countries as well as in Europe.

1 Introduction

Findings from comparative studies of regulatory acoustic requirements and acoustic classification schemes in Europe have shown significant differences across Europe. Acoustic regulations and acoustic classification criteria are typically about the following performance areas for the finished building: Airborne and impact sound insulation; Traffic noise, i.e. airborne sound insulation of facades; Reverberation time or sound absorption; Service equipment noise.

Test methods are usually the ISO measurement and rating methods defined in [1-6] or methods defined in the national building regulations. This paper deals with acoustic regulations in Europe in general, but with special focus on the acoustic regulations in the Nordic countries, see [7-11]. The Nordic countries also have acoustic classification schemes [12-17] with close connection to the building codes [7-11] in four of the five countries. A simplified overview of the building categories in the acoustic classification schemes in the Nordic countries is found in Table 1.

Table 1: Simplified overview of building categories in existing acoustic classification schemes in the Nordic countries.

Coun-try	Acoustic classification scheme (ACS)		Dwel-lings	Schools	Kinder-garten	Healthcare facilities	Offices	Restau-rants	Other
DK	DS 490	[12]	+						
FI	SFS 5907	[13]	+	+	+	+	+		+
IS	IST 45	[14]	+	+	+	+	+	+	+
NO	NS 8175	[15]	+	+	+	+	+	+	+
SE	SS 25267 & SS 25268	[16,17]	+	+	+	+	+	+	+

Examples of acoustic regulations in Europe are found in Section 2, and a brief history of sound insulation descriptors in Section 3. Noise annoyance is briefly dealt with in Section 4. In Section 5 is given an overview of national acoustic classification schemes in Europe for housing. The need for quieter European homes/buildings is dealt with in Section 6, and the opportunities for harmonization in Europe and in the Nordic countries in Section 7. A summary and suggestions for initiatives are found in Section 8.

2 Acoustic regulations Europe – Examples

In most countries in Europe, acoustic building regulations now exist for housing, schools and kindergarten, and in several countries also for other building categories like office buildings, healthcare facilities etc. Since housing has been considered most important for acoustic regulations, we know most about such regulations, and a major part of the descriptions in the following is about dwellings in multi-storey housing. Acoustic regulations for housing specify minimum requirements aiming at protecting health for “normal” people with “normal” neighbours. Such regulations exist in most countries in Europe and define criteria for acoustical conditions in new housing.

Comparative studies of sound insulation requirements between countries for new housing are found in e.g. [19-20] for 24 countries and in [21] for 35 countries. Sound insulation descriptors applied in national sound insulation requirements for dwellings are shown in Table 2 for 31 countries in Europe (since 4 of the 35 countries do not have acoustic regulations). Based on the results presented in the Table 2, the diversity of descriptors applied in Europe is obvious. Sound insulation descriptors are defined in ISO 717 [2], which unfortunately allows a high variety of descriptors, see [20] and Section 3. Detailed, comparative studies of sound insulation descriptors for regulations and classification schemes (housing) are described in [20]. Efforts were and are made to promote harmonization of descriptors in Europe, see e.g. [21].

Table 2: Sound insulation descriptors applied for regulatory requirements between dwellings in 31 countries Europe – Status January 2018.

Airborne sound		Impact sound	
No. of countries	**Descriptor**	**No. of countries**	**Descriptor**
15	R'_w	**17**	$L'_{n,w}$
3	$R'_w + C$	**2**	$L'_{nT,w} + C_{I,50-2500}$
1	$D_{nT,w} + C_{50-3150}$	**9**	$L'_{nT,w}$
7	$D_{nT,w}$	**2**	$L'_{nT,w} + C_I$
3	$D_{nT,w} + C$	**1**	L'_w
1	$D_{nT,A}$ ($\approx D_{nT,w} + C$)	**?**	**Variants**
1	$D_{nT,w} + C_{tr}$	**?**	**Recommendations**
?	**Variants**	**?**	**Special rules**
?	**Recommendations**		
?	**Special rules**		

Since descriptors are different, estimated equivalent values of airborne and impact sound insulation requirements are found for comparison, and the results for current requirements are shown in diagrams in Figures 1 and 2 − which are based on data presented in [21], but updated with revised requirements for Finland, Germany, Slovenia and Sweden and with new requirements for Turkey. From Figures 1-2, it is seen that especially the requirements for impact sound differ considerably across Europe, since the range for airborne is about 7 dB, and for impact about 18 dB. The reasons have not been investigated, but could be a mix of construction traditions and culture etc. For more details about regulations and constructions, see [19] and [21-22]. It could be interesting and relevant to get information about occupants’ satisfaction with the acoustic conditions in different countries.

Regulations are most often for new-build only, although some countries have regulations or recommendations for renovated buildings. If acoustic regulations did not exist or were not enforced or were too weak, when the buildings were designed and constructed, there is a high risk of insufficient acoustic performance, cf. Section 6.

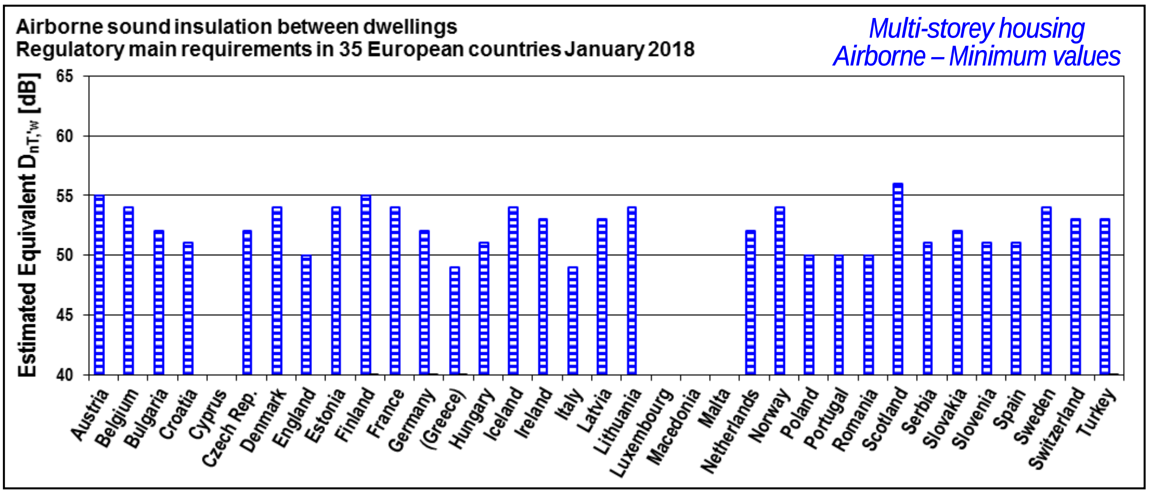

Figure 1: Overview of airborne sound insulation requirements between dwellings. Status January 2018. Graphical presentation of estimated equivalent values of $D_{nT,w}$.

Note: The equivalent values are estimates only, as exact conversion is not possible.

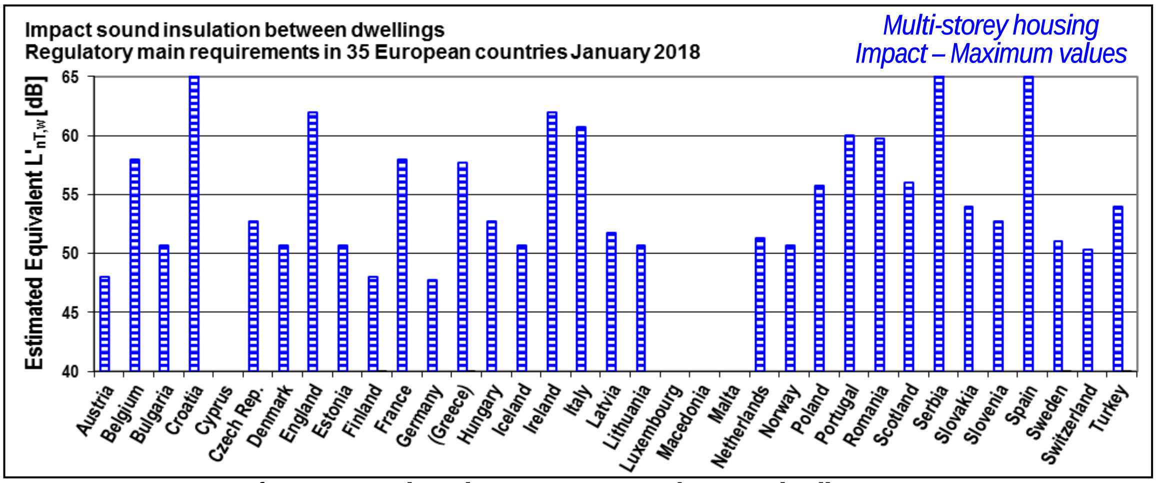

Figure 2: Overview of impact sound insulation requirements between dwellings. Status January 2018. Graphical presentation of estimated equivalent values of $L'_{nT,w}$.

Note: The equivalent values are estimates only, as exact conversion is not possible.

Other comparative studies of acoustic requirements and/or classification have been made, although less extensive concerning number of countries and less detailed. Examples are e.g.:

- Sound insulation between dwellings and indoor traffic noise limits, Nordic countries, 2012, [23].
- Sound insulation between classrooms, indoor traffic noise limits and reverberation time, Nordic countries, 2016, [24].
- Sound insulation between classrooms, facade sound insulation, service equipment noise and reverberation time, six countries in Europe, 2016, [25].
- Dwellings and classrooms, sound insulation between rooms, facade sound insulation, service equipment noise and reverberation time, six countries in Europe and three in South America, 2016, [26].
- Offices and hospital bedrooms, sound insulation between rooms, indoor traffic noise limits, service equipment noise and reverberation time, Nordic countries, 2017, not published.

In most of these studies, it is found that levels of requirements as well as descriptors vary considerably between countries. For sound insulation and reverberation time, least differences are found in the Nordic countries, but for indoor traffic noise limits and service equipment noise, it seems as if none of these countries use identical descriptors. Furthermore, [27-28] deal with comparison of classification for housing in Europe.

Based on findings for housing, schools, office buildings and hospitals, there is a high potential for cooperation in Europe and especially in the Nordic countries having – in spite of many differences –more similar basic regulations.

3 Brief history of acoustic descriptors in building codes

The acoustic descriptors applied in building regulations are defined in the ISO standards [1-6] for measurement and rating, although some countries apply additional national variants or conditions. Within building acoustics, ISO standards are usually implemented as European (EN) standards and national standards. Since sound insulation descriptors create most discussions between countries, a historical overview of ISO 717 descriptors is found in Table 3 and the current variety is found in Table 4. Both tables provide useful information, when comparing between countries, cf. Table 2, or comparing the development of national requirements over time. Before the first version, requirements were often “comparative”, e.g. requiring a performance as good as a 1/1 stone brick wall, or by using other descriptors, see e.g. [20]. The standard ISO 717 from 1996, see Table 3, has contributed to the diversity in Europe by allowing many different descriptors and by introducing spectrum adaptation terms with different extended frequency ranges, and these are maintained in the most recent version from 2013 [2], see Tables 3 and 4.

Table 3: Historical overview of ISO 717 with indication of main characteristics for airborne and impact sound insulation.

1968	ISO/R 717:1968, “Rating of sound insulation for dwellings” (first edition, 7 pages)	Field descriptors: I_a, I_i 8 dB rule
1982	ISO 717:1982, “Acoustics - Rating of sound insulation in buildings and of building elements” Part 1: Airborne sound insulation in buildings and of interior building elements Part 2: Impact sound insulation Part 3: Airborne sound insulation of facade elements and facades	Laboratory & field: Part 1: R_w, R'_w, D_w, $D_{nT,w}$ Part 2: $L_{n,w}$, $L'_{n,w}$, $L_{nT,w}$ Part 3: Several symbols No 8 dB rule, but unfavourable deviations more than 8 dB shall be reported
1996	ISO 717:1996, “Acoustics - Rating of sound insulation in buildings and of building elements” Part 1: Airborne sound insulation Part 2: Impact sound insulation	Several spectrum adaptation terms: – C, C_{tr}, C_I – Various frequency ranges 50/100-3150/5000 Hz (four ranges)
2013	ISO 717:2013, “Acoustics - Rating of sound insulation in buildings and of building elements” Part 1: Airborne sound insulation Part 2: Impact sound insulation	Same main characteristics as for 1996. Amendments about rounding rules incorporated. Allow weighting steps of 0.1 dB to be used for expressing uncertainties. Updated references to measurement methods/equations.

Table 4: Overview ISO 717 descriptors (1996 and 2013) for evaluation of sound insulation in buildings

ISO 717:2013 descriptors for evaluation of field sound insulation	Airborne sound insulation between rooms (ISO 717-1) (b)	Airborne sound insulation of facades (a) (ISO 717-1) (b)	Impact sound insulation between rooms (ISO 717-2) (b)
Basic descriptors (single-number quantities)	R'_w $D_{n,w}$ $D_{nT,w}$	R'_w $D_{n,w}$ $D_{nT,w}$	$L'_{n,w}$ $L'_{nT,w}$
Spectrum adaptation terms (listed according to intended main applications)	*None* C $C_{50-3150}$ $C_{100-5000}$ $C_{50-5000}$	*None* C C_{tr} $C_{50-3150}$ $C_{tr,50-3150}$ $C_{100-5000}$ $C_{tr,100-5000}$ $C_{50-5000}$ $C_{tr,50-5000}$	*None* C_I $C_{I,50-2500}$
Total number of descriptors	3 x 5 = 15	3 x 9 = 27	2 x 3 = 6

Notes
(a) For facades, the complete indices for R'_w, $D_{n,w}$, $D_{nT,w}$ are found in ISO 717.
(b) For simplicity, only 1/3 octave quantities and C-terms are included in the table, although some countries allow 1/1 octave measurements for field check.

Changes over time and between countries exist for other acoustic descriptors defined in ISO standards or just defined nationally. Examples on comparisons between countries are found in references in Section 2. The current diversity both in the Nordic countries and in Europe is significant and not easy to understand, since in most countries the same ISO standards [1-6] are referred to. For the Nordic countries, it could be mentioned that Sweden and Finland have changed to standardized sound insulation descriptors for housing, see [8, 11], and the descriptors for indoor traffic noise limits and service equipment show an unexpected high variety between the Nordic countries.

4 Noise annoyance and reactions

Reasons for noise and acoustic regulations implemented by authorities are negative impacts of traffic noise, neighbour noise and other noises on building users' health. In everyday life, we are exposed to many different sounds and noises. Some of these are pleasant, others disturb or annoy. Noise interferes with communication, disturbs sleep and other activities and may cause annoyance. For traffic noise, the link between exposure and response is given by reasonably well established exposure-response curves, which are derived from research into noise effects. Noise indicators, such as L_{den} and L_{night} defined in [18], describe the exposure situation. At the same equivalent noise level, annoyance is usually higher for aircraft noise than for road traffic and railways, see Figure 3, which also includes annoyance from wind turbines.

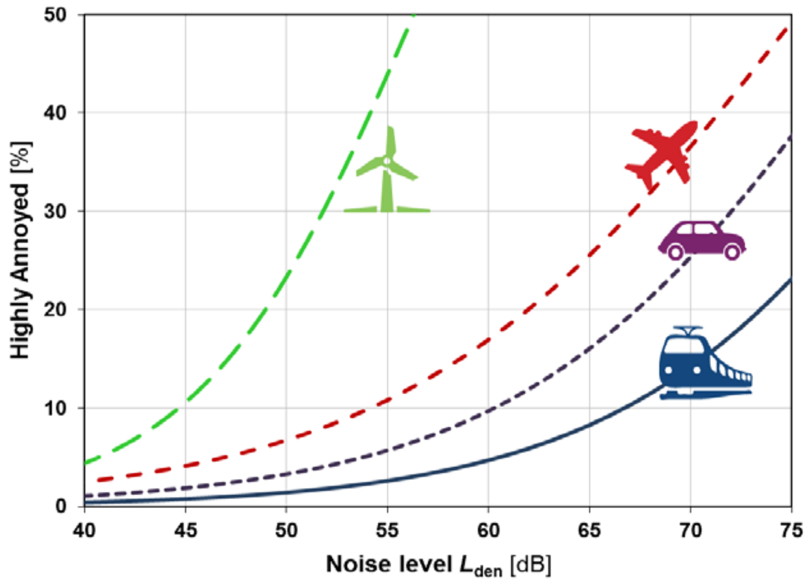

Figure 3: Percentage of people highly annoyed by noise from air, road, railway traffic (data from [29]) and wind turbines 8 m/s (data from [30]).

Note: The traffic noise annoyance curves are being reconsidered for adjustments, although the principles and order are the same.

Noise exposure from traffic can be objectively quantified by physical parameters and the related annoyance found, cf. e.g. Figure 3. In contrast, various neighbour noises are more complex and in general not quantifiable, because they are largely unpredictable and typically with a very high informational content. The perceptions of such noises are individual and subjective and are often assessed by means of survey questions targeting noise annoyance. Examples of surveys from UK, France, Netherlands, Denmark and Norway are found in [31-36], and especially the noise survey in UK is very extensive and reported in detail, see [32].

If the sound insulation between dwellings is insufficient, disturbance of activities and sleep disturbance are typical consequences, see e.g. Table 5, and reactions may go in different directions, e.g. annoyance may develop to hatred and conflicts or disturbance to tension, depression and tiredness, cf. Figure 4 and description of the noise reaction process in [37]. Another consequence of insufficient sound insulation might be that occupants choose to renounce on own activities and feel compelled to avoid certain activities from the household, because they fear neighbours' feelings or reactions - or they know by experience that neighbours get disturbed or annoyed. A typical example could be that parents prevent small children from playing in the home due to complaints from neighbours, and sooner or later they might choose to move to housing with better sound insulation or a one-family house. Neighbour noises may lead to conflict between neighbours, and there are reasons to suspect that neighbour noise annoyance affects health. These brief explanations illustrate a few of many examples on how the social well-being can suffer from insufficient sound insulation.

WHO has defined health as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity", cf. [38]. As a consequence, noise effects on health should not simply be understood as the adverse physical effects due to noise exposure, but also as disturbance of well-being, i.e. psychological effects of noise, which in the long term may lead to not only lack of well-being, but also to adverse physical effects. These effects can be medical conditions, but can also include sleep disturbance, stress etc. - Acoustical well-being can be characterized as absence of unwanted sound, presence of desired sounds with the right level and quality and opportunities for activities without being heard by other people or annoying them. Acoustical well-being is thus also related to own and neighbours' privacy and to freedom to practise activities within reasonable limits, see Table 5.

Table 5: Examples of disturbing/annoying neighbour sounds and own activities being disturbed.
Note: see also Table 9 in Section 6 about lack of privacy and restraints on own activities.

Disturbing/annoying neighbour noises		Own activities disturbed
♦ Voices/shouting/arguments ♦ Dogs ♦ Radio, TV, music ♦ Parties ♦ Neighbours' DYI	♦ Footsteps ♦ Children jumping/playing ♦ Doors banging ♦ Washing machines etc.	♦ Sleeping ♦ Using every room in the house ♦ Listening to TV, radio, music ♦ Quiet activities: Studying, reading, resting ♦ Having a conversation

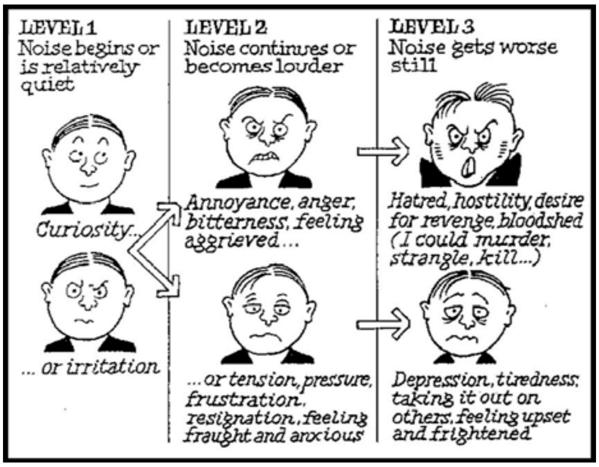

Figure 4: The noise reaction process. From [37].

The population in EU-28 is over 500 million inhabitants, and there are above 200 million dwellings according to Eurostat or other sources. Concerning the housing stock in Europe and acoustic conditions, country descriptions are found in [22]. Eurostat has published census data about population and housing and various reports, see website [39]. *In* 2014, 4 out of every 10 persons in the EU-28 lived in flats. Distribution of dwelling types for the individual countries in EU28+, sorted according to decreasing % of flats in the countries is found at [39], see also brief information in [40].

A potential, adverse influence on health is the main reason for having minimum airborne and impact sound insulation requirements in many countries, but the requirements are typically valid for new housing. However, a big part of the housing stock in Europe has been built before implementation of building regulations, and with a sound insulation typically much lower than for new housing. In addition, improvements of sound insulation are seemingly seldom included in housing renovation, e.g. due to lack of knowledge, focus, policies and regulations.

When considering promoting sound insulation improvements in renovation projects, the basis for discussion and development of tools is information about the existing housing stock, the previous and current national requirements for new housing as well as the systems, decision processes and practices applied for renovation of existing housing. As neighbour noise is a bigger problem in flats than in other types of housing, highest priority should be given to multi-storey housing. As an example, the Danish survey [35] showed that 33% of people living in such housing were annoyed by neighbour noise, while it was less than 10% among people living in row, double and detached houses. The year of construction is important to identify construction types and evaluate sound insulation, especially from before regulations existed. As construction practice varies across Europe, this should be done on a national basis, see example in Section 6.

On the EU level, the noise policy relates to environmental noise [18], and the status is described in e.g. [41-42]. EU does not have a policy on noise in buildings, e.g. neighbour noise is not included. Concerning national noise policies, they relate typically to the EU policy and thus in general to environmental noise only. A wider noise policy – worth to copy – is found for England, where the government (DEFRA) has prepared the *Noise Policy Statement for England* (NPSE), [43], which also includes neighbour noise: *"Noise Policy Vision: Promote good health and a good quality of life through the effective management of noise within the context of Government policy on sustainable development."* … *"This NPSE should apply to all forms of noise including environmental noise, neighbour noise and neighbourhood noise. The NPSE does not apply to noise in the workplace (occupational noise)."*

Noise policies including neighbour noise seem to be missing in other countries, but could definitely be worthwhile discussing and implementing at both a European level and in the individual countries.

5 Acoustic classification for housing - Overview schemes in Europe

This Section is primarily about acoustic classification schemes for housing. Complying with regulatory requirements does not guarantee satisfactory conditions for the occupants, and since the mid 1990'es, several countries have developed and introduced schemes with acoustic classes reflecting different levels of acoustical comfort/protection. For most schemes, the purpose has been and still is to make it easier for developers to specify and for users to require a standardized acoustic quality better than the quality defined by regulations, and thus lower classes for old buildings are often missing.

An overview of existing national acoustic classification schemes in Europe for dwellings, [12-17] and [44-51], is found in Table 6. For each scheme listed, the class denotations, number of classes and the relation to the national building code are indicated. Information about an international proposal is found in [52] and [53]. Tables with specific main class criteria for airborne and impact sound insulation are found in [27], although some data need to updating. Table 6 also includes number of classes below the national regulations.

Table 6: European schemes for acoustic classification of dwellings, [12-17] and [44-51], relation to building codes and information about number of classes. ISO/DIS 19488 (2017), [52], has been included for comparison.

Acoustic classification of dwellings - Schemes in Europe and relation to building codes – Status January 2018							
Coun-try	Year of publication	CS Reference (latest version)	Class denotations(1)	BC link to CS	BC ref. to CS & Comments	No. of classes	No. of classes < BC
DK	2001/2007	DS 490 (2007)	A / B / C / D	+	Class C	4	1
FI	2004	SFS 5907 (2004)	A / B / C / D	–	N/A (BC ~ Class C)	4	1
IS	2003/2011/2016	IST 45 (2016)	A / B / C / D	+	Class C	4	1
NO	1997/2005/2008/2012	NS 8175 (2012)	A / B / C / D	+	Class C	4	1
SE	1996/1998/2004/2015	SS 25267 (2015)	A / B / C / D	–	N/A (See note(4))	4	1
LT	2003	STR 2.01.07 (2003)	A / B / C / D / E	+	Class C	5	2
IT	2010	UNI 11367 (2010)	I / II / III / IV	–	N/A (BC ~ Class III	4	1
DE	1994/2007/2012	VDI 4100 (2012)(2)	III / II / I	–	N/A (BC ~ Class I(2))	3	~ 0
DEGA	2009/2018	DEGA Empfehlung 103 (2018)(3)	A*/ A / B / C / D / E / (F)	–	N/A (BC ~ Class D(3))	6+npd	1+npd
AT	2012	ÖNORM B 8115-5(2012)	A / B / C / D / (E)	–	N/A (BC = Class C)	4+npd	1+npd
NL	1999	NEN 1070 (1999)	I / II / III / IV / V	–	N/A (BC ~ Class III)	5	2
TR	2017	Noise Protection and sound insulation in Buildings(6)	A/B/C/D/E/F	+	Class C	6	3
ISO/WI	ISO/WI 19488 since 2014	ISO/DIS 19488 (Sept. 2017)	A/B/C/D/E/F and npd	N/A	N/A (See note(5))	6+npd	N/A

Abbreviations: BC = Building Code (regulatory requirements); CS = Classification scheme

(1) Classes are indicated in descending order, i.e. the best class first. Denotations in brackets correspond to npd.

(2) The revised version of VDI 4100 published in 2012 changed descriptors from R'_w and $L'_{n,w}$ to $D_{nT,w}$ and L'_{nT} (as had been discussed for years for the regulations), and class criteria were made stricter, i.e. above and regulations. After tightening of DIN 4109-1 in 2016, the basic criteria for the lowest class I for MS-housing are again similar to regulations, but VDI 4100 has additional criteria, e.g. on internal sound insulation.

(3) In addition to VDI 4100, the German Society of Acoustics (DEGA) has published a recommendation, DEGA-Empfehlung 103, "Schallschutz im Wohnungsbau – Schallschutzausweiz". For MS-housing, Class D criteria in general correspond to regulations, but there are additional criteria.

(4) SS 25267 (2015) does not include class C criteria, but refers to values in the BC as class C.

(5) Original proposal prepared by COST TU0901 in 2013. ISO/WI 19488 from 2014, ISO/DIS in Sept. 2017.

(6) "Noise Protection and Sound Insulation in Buildings" www.resmigazete.gov.tr/eskiler/2017/05/20170531-7.htm (May2017).

The airborne and impact sound insulation descriptors applied in the classification schemes for housing in Table 6 are found in Tables 7 and 8, and the quality class ranges and regulations can be found in diagrams in [28] and [40].. Comparing the data from the classification schemes in Europe, see Tables 6-8, and detailed class criteria in the references (see e.g. Table 6), several differences are found, see e.g. [28] and [40]. The tables 7-8 also show the variety of descriptors applied in the acoustic classification schemes in Europe, including the Nordic countries.

It is obvious that acoustic classification could be relevant for existing housing before renovation by using lower classes suitable for existing housing, if available. From Table 6 it is seen that the five Nordic countries and Italy have one quality class below regulations, Lithuania and the Netherlands have two classes, Austria and Germany (DEGA 103) 1+npd, and Turkey three classes below regulations. Germany (VDI 4100) has none, thus following the original idea of acoustic classes to be only/mainly for specifying better acoustic conditions than regulations. To sum up briefly, the existing acoustic classification schemes do not in general include acoustic classes fitting major parts of the existing housing stock. In [54], which includes mapping of the Danish housing stock, i.e. number of dwellings according to construction year, constructions and estimated sound insulation, it is suggested to extend the present DS 490 [12] with two lower classes E and F suitable for older housing, see also Section 6. Such extension could pave the road for a future acoustic labelling in a similar way as for the mandatory energy labelling used also for existing buildings, both housing and many other building categories. In Lithuania, Italy and Turkey, the acoustic schemes include e.g. schools, kindergarten, hospitals and office buildings. For the Nordic countries, see Table 1.

Table 7: Airborne sound insulation between dwellings. Descriptors in acoustic classification schemes in Europe.

Airborne sound insulation between dwellings - Descriptors for class criteria – Status January 2018							
Country (1)	Class A NL, IT: Class I DE: Class III	Class B NL, IT: Class II DE: Class II	Class C NL, IT: Class III DE: Class I	Class D NL, IT: Class IV DE: N/A	Class E NL: Class V IT, DE: N/A	Class F	BC reference to CS
DK	$R'_w + C_{50\text{-}3150}$	$R'_w + C_{50\text{-}3150}$	R'_w	R'_w	N/A	N/A	Class C
FI	$R'_w + C_{50\text{-}3150}$	$R'_w + C_{50\text{-}3150}$	R'_w	R'_w	N/A	N/A	None (BC ~ Class C)
IS	$R'_w + C_{50\text{-}3150}$	$R'_w + C_{50\text{-}3150}$	R'_w (4)	R'_w	N/A	N/A	Class C
NO	$R'_w + C_{50\text{-}5000}$	$R'_w + C_{50\text{-}5000}$	R'_w (4)	R'_w	N/A	N/A	Class C
SE	$D_{nT,w} + C_{50\text{-}3150}$	$D_{nT,w} + C_{50\text{-}3150}$	$(D_{nT,w} + C_{50\text{-}3150})$	$D_{nT,w} + C$	N/A	N/A	None (Class C = BC)
LT	$R'_w + C_{50\text{-}3150}$ or $D_{nT,w} + C_{50\text{-}3150}$	$R'_w + C_{50\text{-}3150}$ or $D_{nT,w} + C_{50\text{-}3150}$	R'_w or $D_{nT,w}$ (4)	R'_w or $D_{nT,w}$	R'_w or $D_{nT,w}$	N/A	Class C
IT*	R'_w	R'_w	R'_w	R'_w	N/A	N/A	None (BC ~ Class III)
DE** (2)	$D_{nT,w}$	$D_{nT,w}$	$D_{nT,w}$	N/A	N/A	N/A	None (BC < Class I)
AT (3)	$D_{nT,w} + C_{50\text{-}3150}$	$D_{nT,w} + C_{50\text{-}3150}$	$D_{nT,w}$	$D_{nT,w}$	$D_{nT,w}$	N/A	None (BC = Class C)
NL***	$D_{nT,w} + C$	$D_{nT,w} + C$	$D_{nT,w} + C$	$D_{nT,w} + C$	$D_{nT,w} + C$	N/A	None (BC ~ Class III)
TR	$D_{nT,w} + C$	$D_{nT,w} + C$	$D_{nT,w} + C$	$D_{nT,w} + C$	$D_{nT,w} + C$	$D_{nT,w} + C$	Class C
ISO/DIS (5)	$D_{nT,w} + C_{50\text{-}3150}$	$D_{nT,w} + C_{50\text{-}3150}$	$D_{nT,w} + C$	$D_{nT,w} + C$	$D_{nT,w} + C$	$D_{nT,w} + C$	N/A

* Classes I, II, III, IV; ** Classes III, II, I; *** Classes I, II, III, IV, V
(1) For references to the standards describing the classification schemes, see separate information.
(2) The classification scheme VDI 4100 has separate class criteria for multi-storey and row housing, the latter being 9-10 dB stricter. In addition, there is another scheme, DEGA-Empfehlung 103 with 6 classes A*-E and class F = npd, descriptor R'_w applied.
(3) For row housing, Class C has a special 5 dB stricter criterion to match the building regulations; the class is denoted C_R.
(4) Use of $C_{50\text{-}3150/5000}$ is recommended also in Class C. If applied, the limit value may be reduced, see references.
(5) The descriptors indicated are from ISO/DIS 19488 (Sept. 2017).

Table 8: Impact sound insulation between dwellings. Descriptors in acoustic classification schemes in Europe.

Impact sound insulation between dwellings – Descriptors for class criteria - Status January 2018							
Country(1)	Class A NL, IT: Class I DE: Class III	Class B NL, IT: Class II DE: Class II	Class C NL, IT: Class III DE: Class I	Class D NL, IT: Class IV DE: N/A	Class E NL: Class V IT, DE: N/A	Class F	BC reference to CS
DK	$L'_{n,w}$ and $L'_{n,w} + C_{I,50\text{-}2500}$	$L'_{n,w}$ and $L'_{n,w} + C_{I,50\text{-}2500}$	$L'_{n,w}$	$L'_{n,w}$	N/A	N/A	Class C
FI	$L'_{n,w}$ and $L'_{n,w} + C_{I,50\text{-}2500}$	$L'_{n,w}$ and $L'_{n,w} + C_{I,50\text{-}2500}$	$L'_{n,w}$ (4)	$L'_{n,w}$	N/A	N/A	None (BC ~ Class C)
IS	$L'_{n,w}$ and $L'_{n,w} + C_{I,50\text{-}2500}$	$L'_{n,w}$ and $L'_{n,w} + C_{I,50\text{-}2500}$	$L'_{n,w}$ (4)	$L'_{n,w}$	N/A	N/A	Class C
NO	$L'_{n,w}$ and $L'_{n,w} + C_{I,50\text{-}2500}$	$L'_{n,w}$ and $L'_{n,w} + C_{I,50\text{-}2500}$	$L'_{n,w}$ (4)	$L'_{n,w}$	N/A	N/A	Class C
SE	$L'_{nT,w}$ and $L'_{nT,w} + C_{I,50\text{-}2500}$	$L'_{nT,w}$ and $L'_{nT,w} + C_{I,50\text{-}2500}$	($L'_{nT,w}$ and $L'_{nT,w} + C_{I,50\text{-}2500}$)	$L'_{nT,w}$	N/A	N/A	None (Class C = BC)
LT	$L'_{n,w} + C_{I,50\text{-}2500}$	$L'_{n,w} + C_{I,50\text{-}2500}$	$L'_{n,w}$ (4)	$L'_{n,w}$	$L'_{n,w}$	N/A	Class C
IT*	$L'_{n,w}$	$L'_{n,w}$	$L'_{n,w}$	$L'_{n,w}$	N/A	N/A	None (BC ~ Class III)
DE** (2)	$L'_{nT,w}$	$L'_{nT,w}$	$L'_{nT,w}$	N/A	N/A	N/A	None (BC <Class I)
AT (3)	$L'_{nT,w}$, $L'_{nT,w} + C_I$ and $L'_{nT,w} + C_{I,50\text{-}2500}$	$L'_{nT,w}$ and $L'_{nT,w} + C_I$	$L'_{nT,w}$	$L'_{nT,w}$	$L'_{nT,w}$	N/A	None (BC = Class C)
NL***	$L'_{nT,w} + C_I$	$L'_{nT,w} + C_I$	$L'_{nT,w} + C_I$	$L'_{nT,w} + C_I$	$L'_{nT,w} + C_I$	N/A	None (BC ~ Class III)
TR	$L'_{nT,w}$	$L'_{nT,w}$	$L'_{nT,w}$	$L'_{nT,w}$	$L'_{nT,w}$	$L'_{nT,w}$	Class C
ISO/DIS (5)	$L'_{nT,w}$ and $L'_{nT,w} + C_{I,50\text{-}2500}$	$L'_{nT,w}$ and $L'_{nT,w} + C_{I,50\text{-}2500}$	$L'_{nT,w}$	$L'_{nT,w}$	$L'_{nT,w}$	$L'_{nT,w}$	N/A

* Classes I, II, III, IV; ** Classes III, II, I; *** Classes I, II, III, IV, V
(1) For references to the standards describing the classification schemes, see separate information.
(2) The classification scheme VDI 4100 has separate class criteria for multi-storey and row housing, the latter being 5 dB stricter. In addition, there is another scheme, DEGA-Empfehlung 103 with 6 classes A*-E and class F = npd, descriptor $L'_{n,w}$ applied.
(3) For row housing, Class C has a special 5 dB stricter criterion to match the building regulations; the class is denoted CR.
(4) Use of $C_{I,50\text{-}2500}$ is recommended also in Class C.
(5) The descriptors indicated are from ISO/DIS 19488 (Sept. 2017).

6 Quieter European homes/buildings?

In *Noise in Europe*, [55], outdoor noise pollution is identified as a growing environmental concern, which is caused by various sources and is widely present not only in the busiest urban environments, but across the countries. It is also pervading once natural environments. *"The adverse effects can be found in the well-being of exposed human populations, in the health and distribution of wildlife on the land and in the sea, in the abilities of our children to learn properly at school and in the high economic price society must pay because of noise pollution"* (quoted from [55]). Due to adverse effects of noise, EU prepared the Environmental Noise Directive (END 2002/49), [18], requiring EU member states to assess exposure to noise from key transport and industrial sources and make action plans, applying the following the following steps: (1) Informing and consulting the public; (2) Strategic noise mapping every 5 years (2007, 2012, 2017…); (3) Action plans every 5 years (2008, 2013, 2018…). - Extensive efforts are done to make vehicles, roads etc. quieter. The strategic noise mapping includes mapping of quiet areas (outdoor), see also [56-57].

However, according to [58-59], 508 million European citizens spend about 90% of their time *indoors*, 2/3 of this time in their homes and 1/3 in workplaces, schools, and public spaces. Therefore Europe's buildings have a major impact on Europeans' health, but similar attention on a national or European level was not given to indoor noise, although some national neighbour noise surveys indicate that more people could be annoyed by neighbour noise than by traffic noise. Examples of four representative national surveys (UK, NL, FR and DK) and one non-representative survey (NO) are described in [31-36]. Adverse implications on home life seem to be the same, i.e. sleep disturbances, use of rooms, quiet activities (reading, writing, resting), having a conversation, listening to music/radio/TV. Disturbing/annoying neighbour noise sources are e.g. voices, shouting, arguments, dogs, music/radio/TV, footfall noise and playing children.

Unfortunately, objective information about the acoustic conditions for buildings is not mandatory and rarely available. This is regrettable, since e.g. a dwelling is often the biggest investment during most peoples' lifetime, much time is spent in the dwelling, and acoustic protection is important to the quality of life, both day and night.

In contrast, quality labelling has in general become more widespread - compulsorily or voluntarily. Several products are labelled and noise data included, cf. e.g. [60] about the mandatory tyre label with specification of fuel efficiency, wet grip and rolling noise, and [61] for household products requiring several characteristics, including noise. For buildings, energy marking is widely used and often mandatory, cf. [62]. Energy Performance Certificates (EPCs) are mandatory whenever a property is built, sold or rented, [62]. The situation is illustrated in Figure 5. Unfortunately, an acoustic quality certificate, see example to the right, is not (yet) mandatory. This is very unsatisfactory to prospective occupants of a dwelling and users of other buildings since the acoustic quality is important and a 'hidden' quality, which is not easily evaluated by other means than by communication of an objective assessment, e.g. labelling with an acoustic class.

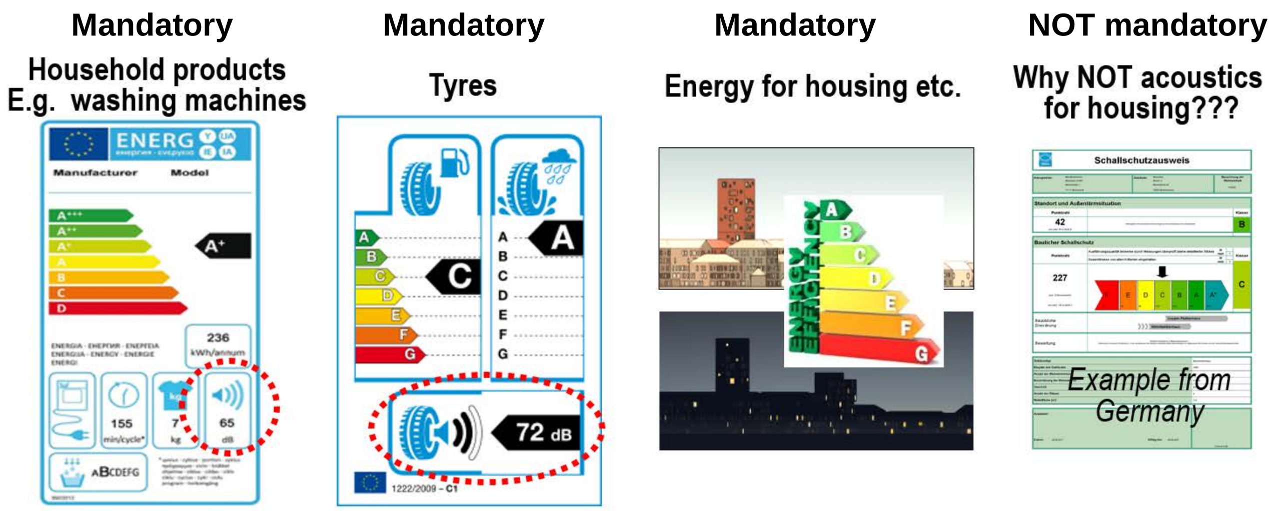

Figure 5: Examples of mandatory labelling in Europe for tyres and household products, both with noise characteristics [60, 61], and for energy labelling of buildings [62]. To the right a voluntary acoustic quality certificate [47].

Acoustic quality classes are described in Section 5. In the below Table 9 are indicated principles and characteristics of acoustic quality classes for housing and the qualitative implications for acoustic protection and comfort, as well as for privacy and freedom to do own activities without disturbing neighbours.

Table 9: Principles and characteristics of acoustic quality classes for housing.

High acoustic protection and comfort ☺	**Acoustic quality class**						☹ **Very low acoustic protection and comfort**
	A	**B**	**C**	**D**	**E**	**F**	
Improved quietness, privacy	←	←	←	←	←	←	
Improved freedom for own activities without disturbing/annoying neighbours	←	←	←	←	←	←	
							Increasing disturbance/annoyance from neighbours, e.g.:
	→	→	→	→	→	→	Footfall noise, playing children
	→	→	→	→	→	→	Music, radio, speech
	→	→	→	→	→	→	Barking dogs

In the before-mentioned Norwegian survey [36], an especially interesting question is included by asking the occupants, if they are worried disturbing the neighbours. It is found that 33% and 37%, respectively, are worried disturbing neighbours due to speech and music, whereas only 17% are worried about disturbing neighbours with footfall noise, which is actually the type of noise disturbing most occupants, but probably an activity, most people don't think about not doing, since it could be considered a natural "right" to walk on one's own floor.

Most European countries have regulatory requirements for sound insulation between dwellings in multi-storey housing, mainly intended and applied for new housing and thus in most countries not including regulations for housing renovation. However, a major part of the European housing stock was constructed before there were any acoustic regulations – or they were weak or not enforced – and thus a high part of the building stock suffer from unsatisfactory acoustic conditions. Extensive renovation takes place all over Europe, but unfortunately, legislation is in general not tackling acoustic limits for renovated buildings.

In addition, most of the current national acoustic classification schemes for housing do not have acoustic classes suitable for old housing. Considering the ongoing and expected extensive renovation of housing all over Europe, much more attention to improvement of sound insulation between dwellings should be promoted, since the importance to occupants of dwellings is high, evaluated from the prevalence of neighbour noise annoyance in several surveys.

As one example of the situation, the diagram in Figure 6 shows number of Danish dwellings according to year of construction. Regulations were implemented in 1961, but more than half of the dwellings in multi-storey housing were built before that year and most of them have acoustic conditions far below the current limit values. The related construction types and sound insulation characteristics for multi-storey housing in Denmark are found in Figure 7.

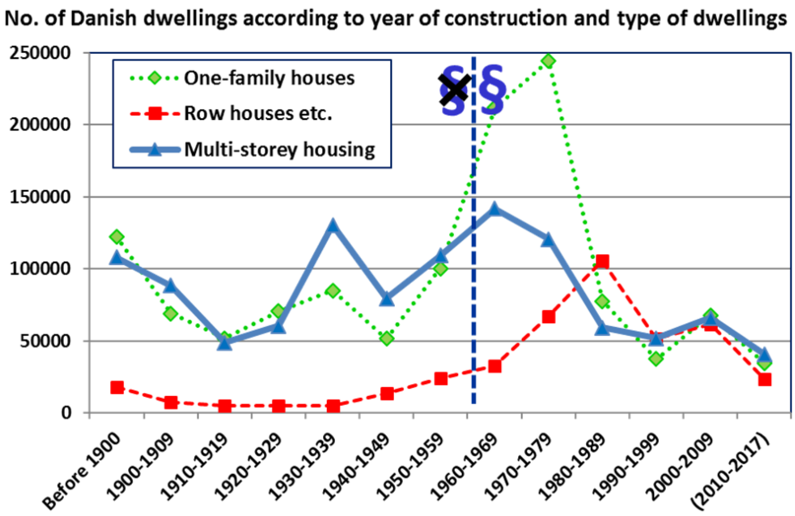

Figure 6: Number of Danish dwellings according to year of construction and type of dwellings in 10 year periods 1900-2009. Source: Statistics Denmark, 2018 [63]. Note: Data for 1900-1919 and 2017 are estimated.

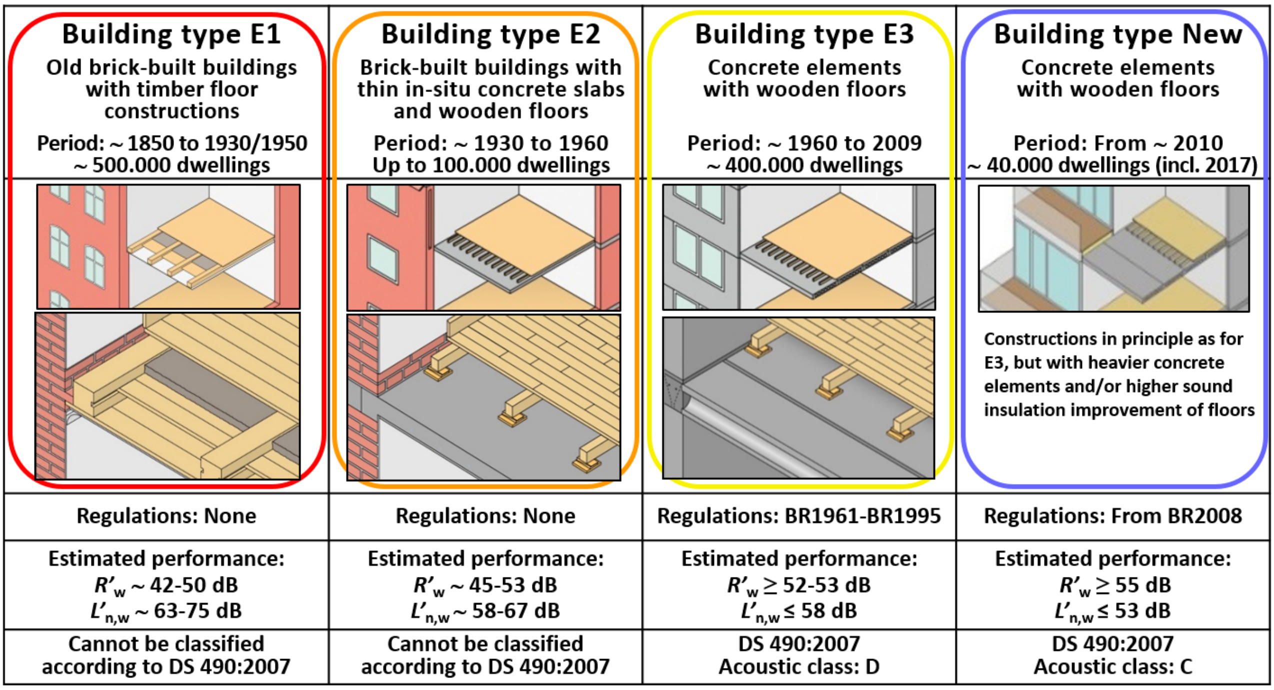

Figure 7: Multi-storey housing stock in Denmark, construction types and sound insulation performance.

Since the acoustic classes in DS 490 [12] do not include the building types E1 and E2 – more than half of the dwellings in Danish multi-storey housing – illustrated in Figure 7, it has been decided to revise DS 490 to include two lower classes E and F. Qualitative descriptions of acoustic classes are useful for communication purposes and for making a qualified choice of class. Thus, verbal descriptions are important. As an example, summarized information based on descriptions in DS 490 [12] is found in Table 10, which also includes the proposed new classes E and F. Another way to characterize acoustic quality classes is to indicate typical neighbour noises like speech (normal, raised, loud), walking, installations, music, television, parties, and for each type of noise describe the perception corresponding to the different acoustic classes. Examples are found in detailed tables in VDI 4100 [46] and DEGA 103 [47].

Table 10: Occupants' expected satisfaction for different sound classes according to DS 490:2007 [12].
Summary based on information in DS 490 and proposed revision.

Sound insulation between dwellings Main class criteria A-D in DS 490:2007 Draft class criteria E-F from proposed revision			Characteristics of DS 490 sound classes for dwellings and occupants' expected evaluation Information from DS 490 and proposed revision		
Class	**Airborne**	**Impact**	**Sound class descriptions**	Good or very good	**Poor**
A	$R'_w + C_{50\text{-}3150} \geq 63$ dB	$L'_{n,w} \leq 43$ dB and $L'_{n,w} + C_{I,50\text{-}2500} \leq 43$ dB	Excellent acoustic conditions. Occupants will be disturbed only occasionally by sound or noise.	**> 90 %**	
B	$R'_w + C_{50\text{-}3150} \geq 58$ dB	$L'_{n,w} \leq 48$ dB and $L'_{n,w} + C_{I,50\text{-}2500} \leq 48$ dB	Significant improvement compared to minimum in class C. Occupants may be disturbed sometimes.	**70 to 85 %**	**< 10 %**
C	$R'_w \geq 55$ dB	$L'_{n,w} \leq 53$ dB	Sound class intended as the minimum for new buildings.	**50 to 65 %**	**< 20 %**
D	$R'_w \geq 50$ dB	$L'_{n,w} \leq 58$ dB	Sound class intended for older buildings with less satisfactory acoustic conditions, e.g. for renovated dwellings.	**30 to 45 %**	**25 to 40 %**
Draft E	Draft $R'_w \geq 45$ dB	Draft $L'_{n,w} \leq 63$ dB	Sound class intended for older buildings with unsatisfactory acoustic conditions.	**10 to 25 %**	**45 to 60 %**
Draft F	Draft $R'_w \geq 40$ dB	Draft $L'_{n,w} \leq 68$ dB	Sound class intended for older buildings with clearly unsatisfactory acoustic conditions.	**< 5 %**	**65 to 80 %**
References: "Lydklassifikation af boliger" (Sound classification of dwellings), versions DS 490:2007 and proposed revision			**Note:** Within each sound class the percentage of satisfied or dissatisfied occupants may depend on the type of criterion. The grouping is mainly based on the subjective assessments of airborne and impact sound from adjacent dwellings.		

Similar considerations could be made for other building categories than housing, e.g. schools, hospitals, office buildings. Construction solutions for upgrading of sound insulation are available, although some solutions would benefit considerably from further research and optimization.

Inspired by the “END” for outdoor noise, cf. start of Section 6, it could be recommended to prepare a mapping of acoustic indoor conditions for buildings with highest priority for housing:

- Number of dwellings as a function of construction year/period and descriptions of related construction types.
- Acoustic performance (see Section 1 for performance areas in typical acoustic regulations), preferably also quantified by an acoustic class. The history of national acoustic regulations will be useful for this step.
- Need for upgrading, identification of solutions, action plans.

The mapping information could be registered by extending one of the existing EU databases (e.g. the new EU Building Stock Observatory, [64]), which until now seem to be mainly for support of energy efficiency improvements. From the new data in this database, quantification of buildings from various periods and construction systems can be made. Solutions for acoustic improvement could be added in the database and applied for estimation of costs.

Concluding questions for this Section:

- Quiet outdoor areas are found important, cf. [18, 56, 57]. Why is the importance of indoor quiet spaces not discussed? People spend in average 90% of their time indoor!
- Why do most building regulations not include acoustic requirements for renovated buildings? (like for energy).
- Why is acoustic labelling of buildings not mandatory? Cf. with mandatory energy labelling and mandatory, acoustic noise declaration for household machines and car tyres. For many users it would be easy to understand the benefits of acoustic labelling and thus know, before moving to a new apartment or other space, if it is a very nice place with acoustic privacy and protection – or acoustic slum.
- Why do acoustic classification schemes not include lower classes for old buildings?

7 Acoustic regulations and classification in Europe and in the Nordic countries – Opportunities for harmonization?

Based on the findings presented in Sections 2, 3 and 5 about acoustic regulations, descriptors and classification schemes, it seems obvious to recommend more harmonization in Europe, see also [19-21, 23, 27-28], but probably difficult. Due to lack of coordination between countries, the schemes in Europe are very different, thus impeding exchange of experience and causing trade barriers. The Nordic countries have had a long tradition for cooperation about acoustic regulations, and a joint Nordic draft proposal from INSTA-B about acoustic classification of dwellings existed in the 1990s. However, lack of consensus and asynchronous revisions of building regulations in the Nordic countries, led to stop of coordination soon after, and differences between the Nordic countries have increased since then. The national schemes were finished and published at different times and since then revised in four of 5 countries, see Table 6. The INSTA-B proposal included dwellings only, but other types of premises, e.g. schools, kindergarten, offices, hotels, healthcare buildings have been implemented in Finland, Iceland, Norway and Sweden, see Table 1. DK is the only Nordic country with no other building categories than housing included.

In a European perspective, there are many similarities between the schemes in the Nordic countries, and the differences could appear to be minor. Nevertheless, when studying all details, it becomes clear that the schemes have diversified over the years, and there are numerous differences impeding exchange of data and experience. Reviving Nordic cooperation about acoustic classification schemes could prove useful now after about 20 years of experience to share. Norway and Iceland have developed very extensive classification schemes including all buildings, i.e. housing, schools, kindergarten, office buildings, hotels, healthcare buildings, restaurants, receptions, cultural buildings, research buildings, industrial buildings, public transportation buildings etc. Considering the national relations between the building code (BC) and the acoustic classification scheme (ACS), they are different, see Tables 6-8 and example for Iceland described in [65].

Based on comparisons between the Nordic countries, suggested first topics for reopening of cooperation could be e.g.:

- National experience with contents of ACS and links between BCs and ACS, see above and Tables 6-8.
- Airborne and impact sound insulation descriptors/limits for dwellings to be discussed after changes in SE and FI, cf. [8, 11], to $D_{nT,w}+C_{50-3150}/D_{nT,w}$ and $L'_{nT,w}+C_{I,50-2500}$.
- Service equipment noise limits and descriptors.
- Traffic noise limits and descriptors.

8 Summary and suggestions

Acoustic regulations and classification schemes typically include limit values for airborne and impact sound insulation, traffic noise, service equipment noise and acoustic absorption or reverberation time.

Acoustic regulations exist for housing, schools and kindergarten in most countries in Europe, and in several countries also for other building categories like office buildings, healthcare facilities etc. Regulations are most often for new-build only, and since a major part of the existing building stock in Europe is constructed before there were any acoustic regulations – or they were weak or not enforced – a high part of the building stock suffer from unsatisfactory acoustic conditions. Both descriptors and levels of requirements vary considerably across Europe.

More than ten countries in Europe have implemented acoustic classification schemes for housing and more than half of the countries also have other building categories included. When comparing all schemes in Europe, significant discrepancies are found between descriptors, number of quality classes, class ranges, class intervals, and class levels vary.

For both acoustic regulations and classification schemes, harmonization of descriptors would facilitate exchange of construction solutions and help in discussing and optimizing acoustic criteria.

Extensive renovation takes place all over Europe, but unfortunately, legislation is in general not tackling acoustic limits for renovated buildings, and the acoustic classification schemes do most often not include classes for old buildings. Thus, there is a high risk that acoustic conditions do not get awareness and don't get upgraded corresponding to upgrades of other building qualities.

One performance area especially important for both new-build and renovation is service equipment noise, where harmonization of descriptors and discussion of limit values could prove useful, because noise could come from various sources, e.g. energy-saving equipment, heating and ventilation systems, water supply and waste water, motorized equipment like roller shutters and garage doors, and thus several new noise sources may be installed in new buildings and when renovating buildings.

To avoid acoustic slum in the future and support the process for acoustic renovation and acoustic upgrading in general, the following initiatives are suggested, cf. Section 6:

- Acoustic mapping of buildings (number of dwellings/units, construction types and year, acoustic performance) and registration of this information in one of the existing EU databases supporting energy efficiency improvements.
- Preparation of acoustic regulations for renovation of buildings.
- Extension of acoustic classification schemes to include classes for old buildings.
- Make acoustic labelling mandatory in the same way as for energy.

An important topic is also the whole structure of a building code and related documents. In many countries, it is very difficult to get a complete overview of acoustic regulations, guidelines and recommendations due to a complex variety of documents published by authorities, institutes, councils, standardization organizations and various other organizations and with no joint document linking those documents together. For many countries, it could be recommended to simplify considerably, e.g. by having – as in Iceland, Norway, Sweden – the acoustic part of the building code referring to a specific acoustic class in a classification scheme, which should include all building applications and thus be the starting point for the acoustic design of any building.

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References

[1] ISO 16283, Acoustics – Measurement of sound insulation in buildings and of building elements – Part 1: Field measurements of airborne sound insulation between rooms, 2014. – Part 2: Field measurements of airborne sound insulation of facade elements and facades, 2015. – Part 3: Field measurements of impact sound insulation of building elements, 2016.

[2] ISO 717:2013, Acoustics – Rating of sound insulation in buildings and of buildings elements. – Part 1: Airborne sound insulation. – Part 2: Impact sound insulation.

[3] ISO 10052:2004, Acoustics – Field measurements of airborne and impact sound insulation and of service equipment sound – Survey method.

[4] ISO 16032:2004, Acoustics – Measurement of sound pressure level from service equipment in buildings – Engineering method.

[5] ISO 10052:2004Acoustics - Field measurements of airborne and impact sound insulation and of service equipment sound - Survey method.

[6] ISO 3382-2:2008, Acoustics – Measurement of room acoustic parameters – Part 2: Reverberation time in ordinary rooms.

[7] *Bygningsreglement 2018* (Building regulations 2018). Danish Transport, Construction and Housing Authority, 2017. Copenhagen, Denmark. http://bygningsreglementet.dk (link to English translation found at the same page). Note: BR2018 refers to *BR2018 Vejledning om lydforhold* (BR2018 Guideline for acoustic conditions). http://bygningsreglementet.dk/Tekniske-bestemmelser/17/Vejledninger.

[8] *Miljöministeriets förordning om ljudmiljön i byggnader, 796/2017* (in Swedish). Miljöministeriet, Helsingfors, 2017. https://www.finlex.fi/sv/laki/alkup/2017/20170796)

[9] *Byggingarreglugerd 2012* - nr. 112/2012 med breytingum (Building regulations 2012 - No. 112/2012 with amendments, latest version 722/2017). https://www.reglugerd.is/reglugerdir/allar/nr/112-2012

[10] *Byggteknisk Forskrift (TEK17). Veiledning om tekniske krav til byggverk.* (Regulations on technical requirements for building works). Direktoratet for byggkvalitet (Norwegian Building Authority). https://dibk.no/byggereglene/byggteknisk-forskrift-tek17/ (https://dibk.no/globalassets/byggeregler/regulation-on-technical-requirements-for-construction-works--technical-regulations.pdf)

[11] Boverkets byggregler, BFS 2011:6 (Building regulations, latest version with amendments BFS 2017:5 – BBR 25). Boverket (Swedish National Board of Housing, Building and Planning). http://www.boverket.se/sv/lag--ratt/forfattningssamling/gallande/bbr---bfs-20116/

[12] DS 490:2007, *Lydklassifikation af boliger*. (Sound classification of dwellings), DK. Note: Under revision.

[13] SFS 5907:2004, *Rakennusten Akustinen Luokitus*, Finland. (English version, 2005: Acoustic classification of spaces in buildings).

[14] IST 45:2016, *Hljóðvist - Flokkun íbúðar- og atvinnuhúsnæðis* (Acoustic conditions in buildings - Sound classification of various types of buildings), Icelandic Standards, Iceland. Note: See description in [65].

[15] NS 8175:2012, *Lydforhold i bygninger - Lydklasser for ulike bygningstyper* (Acoustic conditions in buildings - Sound classification of various types of buildings), Standards Norway.

[16] SS 25267:2015, *Byggakustik – Ljudklassning av utrymmen i byggnader – Bostäder* (Acoustics – Sound classification of spaces in buildings – Dwellings). Swedish Standards Institute, Stockholm, Sweden.

[17] SS 25268:2007 + T1:2017, *Byggakustik - Ljudklassning av utrymmen i byggnader - Vårdlokaler, undervisningslokaler, dag- och fritidshem, kontor och hotell* (Acoustics - Sound classification of spaces in buildings - Institutional premises, rooms for education, preschools and leisure-time centres, rooms for office work and hotels). Swedish Standards Institute, Stockholm, Sweden.

[18] European Parliament. (2002). *DIRECTIVE 2002/49/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 25 June 2002 relating to the assessment and management of environmental noise.* Official Journal of the EU, L 189. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32002L0049&from=EN

[19] Rasmussen, B. (2010). *Sound insulation between dwellings - Requirements in building regulations in Europe*. Applied Acoustics. 71(4):373-385. Available from: 10.1016/j.apacoust.2009.08.011

[20] Rasmussen, B., Rindel JH. (2010). *Sound insulation between dwellings - Descriptors applied in building regulations in Europe*. Applied Acoustics. 71(3), 171-180. Available from: 10.1016/j.apacoust.2009.08.011.

[21] Rasmussen, B., Machimbarrena, M., *Existing sound insulation performance requirements and classification schemes for housing across Europe***.** Ch. 2 in COST Action TU0901 – Building acoustics throughout Europe. Vol. 1: Towards a common framework in building acoustics throughout Europe. DiScript Preimpresion, S. L., 2014. p. 31-54.

[22] Rasmussen, B., Machimbarrena, M., & Fausti, P. (red.) (2014). *COST Action TU0901 – Building acoustics throughout Europe. Volume 2: Housing and construction types country by country*. DiScript Preimpresion, S. L. http://www.costtu0901.eu/tu0901-e-books.html

[23] Rasmussen, B. (2012). *Sound classification of dwellings in the Nordic countries – Differences and similarities between the five national schemes*. Proceedings of BNAM2012. Nordic Acoustic Association. Joint Baltic-Nordic Acoustics Meeting (BNAM), Proceedings, Vol. 2012.

[24] Rasmussen, B. (2016). *Sound insulation and reverberation time for classrooms - Criteria in regulations and classification schemes in the Nordic countries*. Proceedings of BNAM2016, [Paper#49], Stockholm: Nordic Acoustic Association (BNAM), Proceedings, Vol. 2016.

[25] Rasmussen, B. & Guigou-Carter, C. (2016). *A pilot study on acoustic regulations for schools – Comparison between selected countries in Europe*. Proceedings of Inter-Noise 2016 *(pp. 886-893). Hamburg: Deutsche Gesellschaft für Akustik e.V. (DEGA*).

[26] Machimbarrena, M., & Rasmussen, B. (2017). *Acoustic regulations for housing and schools in Europe and South America – A pilot study in 2016*. Meetings on Acoustics. Proceedings, 28 (1), September 2016, 1-10. [015013]. DOI: http://dx.doi.org/10.1121/2.0000459

[27] Rasmussen, B. (2012). *Sound classification of dwellings - Quality class ranges and intervals in national schemes in Europe*. Proceedings of EuroNoise 2012. (p.1178-1183). European Acoustics Association - EAA.

[28] Rasmussen, B (2016). *Acoustic classification schemes in Europe – Applicability for new, existing and renovated housing. Proceedings of the Baltic-Nordic Acoustics Meeting 2016*. Stockholm: Nordic Acoustic Association. BNAM Proceedings, Vol. 2016).

[29] *EU Position paper on Dose-response relationships between transportation noise and annoyance*. ISBN 92-894-3894-0, European Commission, 2002.

[30] Pedersen, T. H. *The "Genlyd" Noise Annoyance Model*. DELTA report AV 1102/07, 2007.

[31] H. Notley, C. J. Grimwood, G.J. Raw, C. Clark, R. Van de Kerckhove, G. Zepidou,*'The UK national noise attitude survey 2012 – the sample, analysis and some results'*, InterNoise 2013.

[32] DEFRA (2014). *National Noise Attitude Survey 2012 (NNAS2012)*. The Department for Environment, Food and Rural Affairs (Defra), UK Government, London. http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=18288

[33] IFOP (2014), *«Les Français et les nuisances sonores»* (The French and the noise nuisance). Ifop pour Ministère de l'Ecologie, du Développement Durable et de l'Energie. RB/MCP N° 112427. http://www.ifop.com/?option=com_publication&type=poll&id=2799 (report and presentation).

[34] Van Poll, H.F.P.M., Breugelmans, O.R.P., Devilee, J.L.A. (2011). *Hinder bezorgdheid en woontevredenheid in Nederland: Inventarisatie Verstoringen 2008* (Annoyance, concern and residential satisfaction in the Netherlands: Annoyance inventory 2008). RVIM Rapport 630741001/2011. Rijksinstituut voor Volksgezondheid en Milieu, Bilthoven.

[35] Rasmussen, B. & Ekholm, O. (2015). *Neighbour and traffic noise annoyance at home - prevalence and trends among Danish adults*. Proceedings of EuroNoise 2015, p. 1895-1900. Maastricht.

[36] A Løvstad, JH Rindel, CO Høsøien, I Milford (2016). *Sound quality in dwellings in Norway – a socio-acoustic investigation.* Proceedings of BNAM 2016, Stockholm, Sweden.

[37] Grimwood CJ. *''Effects of environmental noise on people at home*". BRE information paper IP 22/93; 1993.

[38] Preamble to the Constitution of the World Health Organization as adopted by the International Health Conference, New York, 19 - 22 June 1946; signed on 22 July 1946 by the representatives of 61 states (official Records of the World Health Organization, No. 2, p. 100) and entered into force on 7 April 1948.

[39] http://ec.europa.eu/eurostat/statistics-explained/index.php/Online_publications
Note: Access to statistics and various publications.

[40] Rasmussen, B. (2017). *Sound insulation in multi-storey housing in Europe – Situation Anno 2017 and needs for upgrading*. In Proceedings of InterNoise 2017.

[41] Paviotti, M, Dodds, M, et al. *The EU noise policy after the second round of noise maps and action plans*. Proceedings of InterNoise2013. ÖAL Österreichischer Arbeitsring für Lärmbekämpfung, 2013.

[42] European Commission (2017). *Report from the European parliament and the council on the implementation of the environmental noise directive in accordance with article 11 of directive 2002/49/EC.* COM(2017) 151 final.

[43] *Noise Policy Statement for England (NPSE), DEFRA*, 2010. www.defra.gov.uk; https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69533/pb13750-noise-policy.pdf

[44] STR 2.01.07:2003, Dél Statybos Techninio Reglamento Str 2.01.07:2003, *Pastatu Vidaus Ir Isores Aplinkos Apsauga Nuo Triuksmo* (Lithuanian building regulations. Protection against noise in buildings). Patvirtinimo, Lithuania.

[45] UNI 11367:2010 *Acustica in edilizia – Classificazione acustica delle unità immobiliari – Procedura di valutazione e verifica in opera* (Building Acoustics - Acoustic classification of building units - Evaluation procedure and in-situ measurements).

[46] VDI 4100:2012, *Schallschutz im Hochbau - Wohnungen - Beurteilung und Vorschläge für erhöhten Schallschutz* (Sound insulation between rooms in buildings - Dwellings – Assessment and proposals for enhanced sound insulation between rooms". VDI-Handbuch Lärmminderung. Beuth, Germany.

[47] DEGA-Empfehlung 103 (2018), *"Schallschutz im Wohnungsbau – Schallschutzausweis"*, DEGA, January 2018. https://www.dega-akustik.de/fileadmin/dega-akustik.de/publikationen/DEGA_Empfehlung_103.pdf

[48] ÖNORM B 8115-5:2012. *Schallschutz und Raumakustik im Hochbau - Teil 5: Klassifizierung*. (Sound insulation and room acoustics in buildings - Classification). ÖNORM, Austria.

[49] NEN 1070:1999, *Geluidwering in gebouwen – Specificatie en beoordeling van de kwaliteit* (Noise control in buildings – Specification and rating of quality), Netherlands.

[50] Nurgun Bayazit, Selma Kurra, Bilge Ozbilen and Ayca Sentop (2016). *Proposed methodology for new regulation on noise protection for buildings and sound insulation in Turkey*. InterNoise2016, Hamburg.

[51] *Noise Protection and Sound Insulation in Buildings*. (2017). Republic of Turkey Official Gazette. Turkish Ministry of Environment and Urbanization. www.resmigazete.gov.tr/eskiler/2017/05/20170531-7.htm

[52] ISO/DIS 19488 (2017), *Acoustics - Acoustic classification of dwellings*. Note: ISO/FDIS expected August 2018.

[53] Rasmussen, B. (2014). *International proposal for an acoustic classification scheme for dwellings: background and perspectives*. Proceedings of Inter-Noise 2014, Australian Acoustical Society.

[54] Rasmussen, B. & Hoffmeyer, D. (2015). *Lydisolation mellem boliger i etagebyggeri – Kortlægning og forbedringsmuligheder*. (Sound insulation between dwellings in multi-storey housing - Mapping and possibilities for improvements). Copenhagen, SBi Report No. 2015:27.

[55] European Environment Agency. (2014). *Noise in Europe 2014*. EEA Report No 10/2014. Copenhagen. www.eea.europa.eu/publications/noise-in-europe-2014

[56] European Environment Agency. (2014). *Good practice guide on quiet areas*. EAA Technical report No 4/2014. https://www.eea.europa.eu/publications/good-practice-guide-on-quiet-areas.

[57] European Environment Agency. (2016). *Quiet areas in Europe: the environment unaffected by noise pollution*. EEA Report No.14/2016. www.eea.europa.eu/publications/quiet-areas-in-europe.

[58] WHO (2014). *Combined or multiple exposure to health stressors in indoor built environments*. http://www.euro.who.int/en/health-topics/environment-and-health/air-quality/publications/2014/combined-or-multiple-exposure-to-health-stressors-in-indoor-built-environments.

[59] Ecofys (2017). Andreas Hermelink and Ashok John. *The relation between quality of dwelling, socio-economic status and health in EU28 and its Member States*. https://www.ecofys.com/en/publications/relation-between-quality-of-dwelling-socio-economic-status-and-heal.

[60] European Parliament (2009). *REGULATION (EC) No 1222/2009 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 25 November 2009 on the labelling of tyres with respect to fuel efficiency and other essential parameters*. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:342:0046:0058:en:PDF.

[61] *DIRECTIVE 2010/30/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 19 May 2010 on the indication by labelling and standard product information of the consumption of energy and other resources by energy-related products*. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32010L0030&from=en.

[62] European Union. (2010). *Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings* (Energy Performance Building Directive, EPBD). http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32010L0031&from=EN.

[63] Statistics Denmark, 2018. http://www.statbank.dk/statbank5a/default.asp?w=1536.

[64] *EU Building Stock Observatory*. https://ec.europa.eu/energy/en/eubuildings

[65] Guðmundsson, S (2016). *Acoustic Classification and Building Regulations. Nordic/Baltic Harmonization?* - Proceedings of BNAM2016.