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Published in:
Proceedings of Inter-Noise 2004

Publication date:
2004

Document Version
Publisher's PDF, also known as Version of record

inter·noise 2004
Prague • Czech Republic • August 22–25

The 33rd International Congress and Exposition
on Noise Control Engineering

Sound insulation between dwellings - Classification schemes and building regulations in Europe

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Abstract [778] The paper will present the main characteristics of classification schemes and building regulations in several countries in Europe. While legal sound insulation requirements for dwellings have existed for up to approx. 50 years, classification schemes describing classes of acoustic quality of dwellings have been introduced during the last few years.

A comparison of main characteristics will be made concerning:
(1) Airborne sound insulation between dwellings
(2) Impact sound insulation between dwellings

A comparison of sound insulation requirements in approx. 20 countries shows that the sound insulation requirements differ considerably in terms of descriptors used, frequency range considered and level of requirements. The most recent version of the standard ISO 717 has contributed to the diversity by allowing several descriptors and by introducing spectrum adaptation terms with different - extended - frequency ranges for the evaluation.

There are significant discrepancies between the European classification schemes, among these descriptors, number of quality classes, intervals between classes, levels of classes, common or separate quality classes for multi-storey and terraced housing.

The status of the classification schemes in relation to the legal requirements varies. In some countries the building code and the classification standard are incoherent. In other countries they are strongly "integrated", implying that the building code refers to a specific class in the classification standard rather than describing the requirements. As a consequence, attention is drawn to the fact that the legislative requirements are minimum requirements, and providing an incentive to voluntarily specify and design for a better acoustic quality.

1 INTRODUCTION

In spite of the facts that a dwelling is probably the biggest investment during most people's lifetime, that much time is spent in the dwelling, and that acoustical comfort is very important to the well-being, objective information about the acoustic conditions is rarely available. This is very unsatisfactory to prospective occupants of a dwelling, as acoustic quality is a 'hidden' quality, which is not easily evaluated by other means. Fulfilment of legal requirements does not ensure satisfactory conditions. The different classes in sound classification schemes are intended to reflect different levels of acoustical comfort. From surveys on noise from neighbours, see e.g. [1], [2], [3], [4], [5], it is possible to derive approximate relationships between the acoustic conditions and the expected percentage of people finding the conditions good or satisfactory c.f. [1]. The willingness to pay for increased acoustical comfort is briefly described in Section 2.

An overview of legal main requirements in 24 countries in Europe is found in Section 3. The European classification schemes and some comments on the relation to legal requirements are described in Section 4.

2 ACOUSTICAL COMFORT AND WILLINGNESS TO PAY

Acoustical comfort is a concept that can be characterized by absence of unwanted sound and by opportunities for acoustic activities without annoying other people. In order to achieve acoustical comfort in a building, certain requirements have to be fulfilled concerning the airborne sound insulation, the impact sound insulation and the noise level from traffic and building services.
It is important to observe that acoustic comfort for a person is related to the person both as a receiver of sound, but also as a source of sound. It can be annoying to be exposed to noise from the neighbours, but it can be equally annoying to know that your activities can be heard by other people and may cause annoyance. Poor sound insulation between dwellings can be a cause of conflicts and a cause of restraints of activities, c.f. [6].
In 1995 an investigation was made in Sweden in order to find the desired level of sound insulation of new dwellings, see [7]. 2322 questionnaires were used for the analysis. 65% of the participating people lived in multi-storey housing, 20% in detached housing, 10% in terraced housing, and 5% in other kinds of housing. One of the main questions was about the willingness to pay a higher rent if the sound insulation of the apartment could be significantly improved. The average answer was about 2500 SEK per year.
In summary it can be concluded that around 60% of the population were willing to pay on average a 10% higher rent, if the sound insulation of the dwelling could be improved.

3 LEGAL SOUND INSULATION REQUIREMENTS IN EUROPE

In building acoustics, the frequency range has traditionally been 100–3150 Hz. However, a trend towards lightweight building constructions has increased the low frequency problems, e.g. due to neighbours' music and footfall noise. Thus, a growing need to include the low frequency sound insulation has been recognized. As a consequence the standard, EN ISO 717:1996 [8], for rating of sound insulation opens up the possibility to apply spectrum adaptation terms for an extended frequency range down to 50 Hz by adding so-called C-corrections when specifying the requirements for sound insulation.
The main requirements on airborne sound insulation between dwellings in 24 European countries have been gathered and presented in Table 1. In order to facilitate a comparison between countries, all requirements have been converted into estimated equivalent values of R'_w. For multi-storey housing the range is approximately 50-56 dB, for terraced housing approximately 50-61 dB. Similarly, the main requirements on impact sound insulation are presented in Table 2. For multi-storey housing the estimated equivalent values of $L'_{n,w}$ are in the range 46-63 dB, for terraced housing 44-63 dB. The indicated ranges are ranges of average eq. R'_w and $L'_{n,w}$. The equivalent values R'_w and $L'_{n,w}$ (mean values) are presented graphically in Fig. 1 and 2, respectively. Examples of application of C-corrections are the Swedish requirements, see Table 1 and 2 or [9], class C. Note: The conversion of values between different concepts is highly uncertain, especially when "low-frequency" spectrum adaptation terms - including C_{tr} - are involved
In several countries the sound insulation requirements have originally been based on the actual performance of traditional building constructions, which have been considered to offer a sufficient level of sound insulation. An exception is Austria, where the requirements were based directly on a large survey in 1974; and the strictest requirements in the world are probably found in Austria.
Legal sound insulation requirements have existed and remained essentially the same for approx. 50 years, but during the last few years several countries have implemented or proposed stricter requirements, c.f. Tables 1 - 2 compared to e.g. [2], [10].

Airborne sound insulation between dwellings **Main requirements in 24 European countries 2004**				May 2004	
Country with indication of concept for formulation of requirements		**Multi-storey housing**		**Terraced housing**	
		Req. [dB]	Eq. R'_w (1), (2) [dB]	Req. [dB]	Eq. R'_w (1), (2) [dB]
Denmark	R'_w	≥ 52(5)	52(5)	≥ 55	55
Norway	R'_w(6)	≥ 55(6)	55(6)	≥ 55(6)	55(6)
Sweden	$R'_w + C_{50\text{-}3150}$	≥ 53	~ 55(7)	≥ 53	~ 55(7)
Finland	R'_w	≥ 55	55	≥ 55	55
Iceland	R'_w(2)	≥ 52(4)	~ 52(4)	≥ 55	~ 55
Germany	R'_w	≥ 53(5)	53	≥ 57	57
UK	$D_{nT,w} + C_{tr}$	≥ 45	~ 49-52(7)	≥ 45	~ 49-52(7)
France	$D_{nT,w} + C$	≥ 53	~ 53-56	≥ 53	~ 53-56
Switzerland	$D_{nT,w} + C$	≥ 54	~ 54-57	≥ 54	~ 54-57
Austria	$D_{nT,w}$	≥ 55	~ 54-57	≥ 60	~ 59-62
Netherlands	$I_{lu;k}$	≥ 0	~ 55	≥ 0	~ 55
Belgium(9)	$D_{nT,w}$	≥ 54	~ 53-56	≥ 58	~ 57-60
Italy	R'_w	≥ 50	50	≥ 50	50
Spain(9)	$D_{nT,w} + C_{100\text{-}5000}$	≥ 50	~ 50-53	≥ 50	~ 50-53
Portugal	$D_{n,w}$	≥ 50	~ 50-52	≥ 50	~ 50-52
Poland	$R'_w + C$	≥ 50(5)	~ 51	≥ 52	~ 53
Czech Rep.	R'_w	≥ 52	52	≥ 57	57
Slovakia	R'_w	≥ 52	52	≥ 52	52
Hungary	R'_w	≥ 52	52	≥ 57	57
Slovenia	R'_w	≥ 52	52	≥ 52	52
Estonia	R'_w	≥ 55	55	≥ 55	55
Latvia	R'_w	≥ 54	54	≥ 54	54
Lithuania	$D_{nT,w}$ **or** R'_w	≥ 55	~ 55	≥ 55	~ 55
Russia	I_b	≥ 50	52	(8)	(8)

Notes

(1) Warning: The equivalent values are rough estimates only as no exact conversion is possible.
(2) The equivalent minimum values of R'_w are - except the conversions of $I_{lu;k}$ and I_b - estimated applying the guidelines in [11] and the C data in [12],.
(3) The maximum unfavourable deviation from the reference curve shall be limited to 8 dB.
(4) 55 dB recommended.
(5) Horizontal, requirement for vertical is 1 dB higher.
(6) It is recommended that the same criteria are fulfilled by $R'_w + C_{50\text{-}3150}$.
(7) Assuming heavy constructions, stricter requirement for light-weight constructions
(8) No requirements. Probably the requirements for multi-storey housing are used.
(9) Proposed new requirements.

Table 1: *Overview airborne sound insulation requirements in 24 European countries*

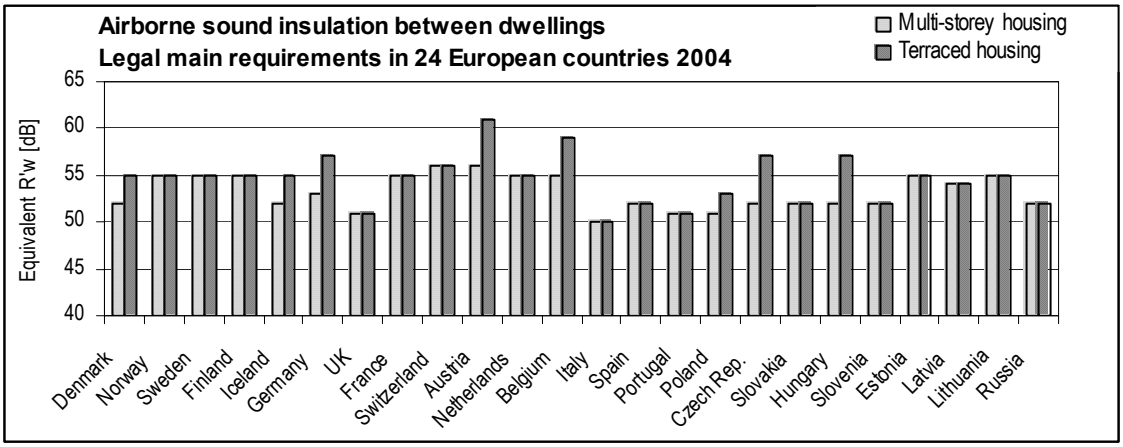

Fig.1: *Overview airborne sound insulation requirements between dwellings. Graphical presentation of equivalent values of R'_w from Table 1. In case of the equivalent R'_w being an interval, the average value has been indicated. Please see the warning in note (1) in Table 1.*

Impact sound insulation between dwellings **Main requirements in 24 European countries 2004**				May 2004	
Country with indication of concept for formulation of requirements		**Multi-storey housing**		**Terraced housing**	
		Req. [dB]	Eq. $L'_{n,w}$ (1), (2) [dB]	Req. [dB]	Eq. $L'_{n,w}$ (1), (2) [dB]
Denmark	$L'_{n,w}$	≤ 58	58	≤ 53	53
Norway	$L'_{n,w}$ (3)	≤ 53 (3)	53 (3)	≤ 53 (3)	53 (3)
Sweden	$L'_{n,w} + C_{i,50\text{-}2500}$	≤ 56 (4)	~ 56 (6)	≤ 56 (4)	~ 56 (6)
Finland	$L'_{n,w}$	≤ 53	53	≤ 53	53
Iceland	$L'_{n,w}$ (3)	≤ 58 (5)	58 (5)	≤ 53	53
Germany	$L'_{n,w}$	≤ 53	53	≤ 48	48
UK	$L'_{nT,w}$	≤ 62	~ 64-57	None	N/A
France	$L'_{nT,w}$	≤ 58	~ 60-53	≤ 58	~ 60-53
Switzerland	$L'_{nT,w} + C_i$	≤ 50	~ 52-45 (6)	≤ 50	~ 52-45 (6)
Austria	$L'_{nT,w}$	≤ 48	~ 50-43	≤ 46	~ 48-41
Netherlands	I_{co}	≥ +5	~ 61-54	≥ +5	~ 61-54
Belgium (8)	$L'_{nT,w}$	≤ 58	~ 60-53	≤ 50	~ 52-45
Italy	$L'_{n,w}$	≤ 63	63	≤ 63	63
Spain (9)	$L'_{nT,w}$	≤ 65	~ 67-60	≤ 65	~ 67-60
Portugal	$L'_{n,w}$	≤ 60	60	≤ 60	60
Poland	$L'_{n,w}$	≤ 58	58	≤ 53	53
Czech Rep.	$L'_{n,w}$	≤ 58	58	≤ 53	53
Slovakia	$L'_{n,w}$	≤ 58	58	≤ 58	58
Hungary	$L'_{n,w}$	≤ 55	55	≤ 47	47
Slovenia	$L'_{n,w}$	≤ 58	58	≤ 58	58
Estonia	$L'_{n,w}$	≤ 53	53	≤ 53	53
Latvia	$L'_{n,w}$	≤ 54	54	≤ 54	54
Lithuania	$L'_{n,w}$	≤ 53	53	≤ 53	53
Russia	I_y	≤ 67	60	(7)	(7)

Notes

(1) Warning: The equivalent values are rough estimates only as no exact conversion is possible.
(2) The equivalent maximum values of $L'_{n,w}$ are - except the conversions of I_{co} and I_y - estimated applying the guidelines in [11] and C data in [12],.
(3) It is recommended that the same criteria are fulfilled by $L'_{n,w} + C_{i,50\text{-}2500}$.
(4) The same criteria shall also be fulfilled by $L'_{n,w}$.
(5) 53 dB recommended.
(6) Assuming heavy constructions, stricter requirement for light-weight constructions
(7) No requirements. Probably the requirements for multi-storey housing are used.
(8) Proposed new requirements.

Table 2: *Overview impact sound insulation requirements in 24 European countries.*

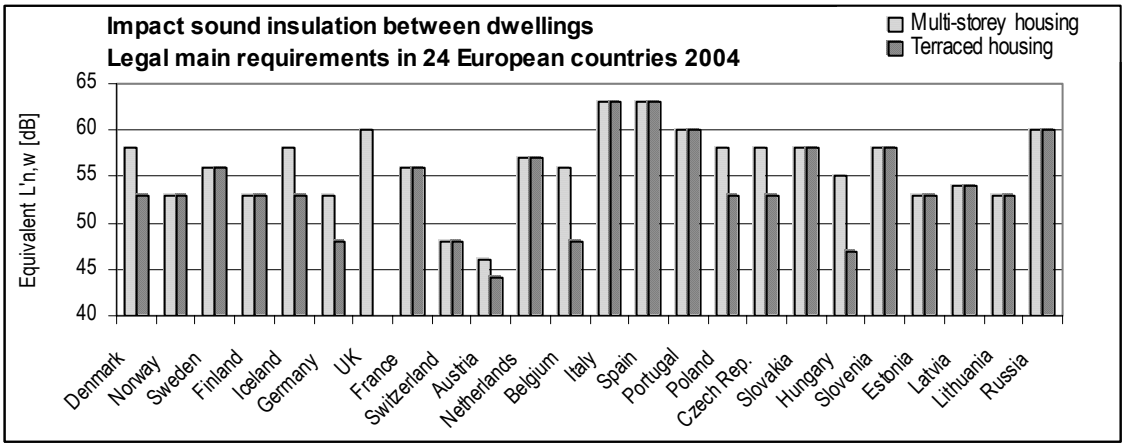

Fig.2: *Overview impact sound insulation requirements between dwellings. Graphical presentation of equivalent values of $L'_{n,w}$ from Table 2. In case of the equivalent $L'_{n,w}$ being an interval, the average value has been indicated. Please see the warning in note (1) in Table 2.*

Significant differences are found when comparing sound insulation requirements in different countries:

Airborne sound insulation
10 concepts + variants/recommendations
For multi-storey housing variation 6 dB in equivalent R'_w
For terraced housing variation 11 dB in equivalent R'_w
The strictest requirements are found in Austria

Impact sound insulation
6 concepts + variants/recommendations
For multi-storey housing variation 17 dB in equivalent $L'_{n,w}$
For terraced housing variation 19 dB in equivalent $L'_{n,w}$
The strictest requirements are found in Austria

The most recent version of the standard EN ISO 717 [8] has contributed to the diversity by allowing different concepts and by introducing spectrum adaptation terms with different - extended - frequency ranges for the evaluation.
Legal requirements concerning sound insulation against traffic noise differ even more than requirements for sound insulation between dwellings due to not only different concepts, but also different principles. Some countries specify the required sound insulation of facades as a function of the outdoor noise level, maybe with different day and night requirements, other countries require the indoor level $L_{A,eq,24h}$ to be below a certain limit. In some countries there are no general, national requirements, but only local. In addition, the methods for determination of the exterior noise exposure vary considerably. In total, the situation is quite complex. On a European level the environmental noise directive 2002/49/EC, see [13], defines two main indicators, L_{den} and L_{night} for description of annoyance and sleep disturbance, respectively.
In order to gather information and share experience more systematically, a working group, EAA TC-RBA WG4 [14], has been established under the European Acoustical Association (EAA), Technical Committee Room and Building Acoustics (TC-RBA). In the future this working group could advise on how to harmonize the use of concepts for sound insulation.

4 SOUND CLASSIFICATION SCHEMES IN EUROPE AND RELATION TO LEGAL REQUIREMENTS

An overview of existing and proposed classification schemes is found in Table 1. The main criteria for airborne and impact sound insulation between dwellings are found in Table 2. Criteria for sound insulation internally in dwellings are found in [15]. The schemes include several other criteria concerning sound insulation and noise levels, see the standards [9], [16], [17], [18], [19], [20], [21], [22], [23]. For lightweight buildings it is important that low-frequency spectrum adaptation terms (down to 50 Hz) according to [8] are included, implying a significantly improved correlation between subjective and objective sound insulation, see [1].

European schemes/proposals for sound classification of dwellings			May 2004
Country	**Class denotations**	**Year of implementation**	**Reference**
Denmark	D / C / B / A	2001	DS 490 (2001)
Norway	D / C / B / A	1997	NS 8175 (1997)
Sweden	D / C / B / A	1996/1998/2004	SS 25267 (2004)
Iceland	D / C / B / A	2003	IST 45 (2003)
Germany - VDI	I / II / III	1994	VDI 4100 (1994)
Germany - E DIN	I / II / III	???? (still draft)	E DIN 4109-10 (February 2002)
France	QL / QLAC	1993/1995/2000	Guide Qualitel (2000)
Netherlands	5 / 4 / 3 / 2 / 1	1999	NEN 1070 (1999)
Lithuania	E / D / C / B / A	2004	STR 2.01.07 (2003)

Table 3: *European schemes/proposals for sound classification of dwellings.*

Concerning sound insulation against traffic noise, the schemes in Norway, DK and Iceland specify max indoor level $L_{A,eq,24h}$ 35 / 30 / 25 / 20 dB for classes D / C / B / A (class C equals legal req.). Sweden has slightly different criteria. The upper class (A) in these schemes seems to be quite strict and maybe not realistic. The German schemes (and legislation) apply a different approach. The sound insulation of the facade is specified as a function of the outdoor level, and Class I and II refer both to the same legal requirements, while class III specify +5 dB higher sound insulation. Future criteria for facades should be expressed by the harmonised environmental noise indicators L_{den} and L_{night} for description of annoyance and sleep disturbance, respectively, see [13].

European schemes/proposals for sound classification of dwellings May 2004
Main criteria for airborne and impact sound insulation between dwellings

Country with indication of class denotation and reference	**Required performance for classes** (1)		***Comments***
	Airborne sound insulation $\mathbf{R'_w}$ **or** $\mathbf{R'_w+C_{50\text{-}3150}}$ [dB]	**Impact sound insulation** $\mathbf{L'_{n,w}}$ **or** $\mathbf{L'_{n,w}+C_{i,50\text{-}2500}}$ [dB]	
Denmark D / C / B / A [6]	≥ 50 / 55 / *58* / 63**	≤ 58 / 53 / *48* / 43**	See note (3)
Norway D / C / B / A [4]	≥ 50 / **55(*)** / 58(*) / 63(*)	≤ 58 / **53(*)** / 48(*) / 43(*)	See note (3)
Sweden D / C / B / A [3]	≥ 49 / ***53**** / *57* / 61**	≤ 60 / ***56**** / *52* /48**	See note (3)
Iceland D / C / B / A [7]	≥ 50 / 55(*) / *58* / 63**	≤ 58 / 53 / *48* / 43**	See note (3)
Germany VDI I / II / III [2]			See note (2)
Multi-storey housing	**≥ 53** / 56 / 59	**≤ 53** / 46 / 39	
Terraced housing	**≥ 57** / 63 / 68	**≤ 48** / 41 / 34	
Germany E DIN I / II / III [9]			See note (2)
Multi-storey housing	**≥ 53** / 56 / 59	**≤ 53** / 46 / 39	
Terraced housing	**≥ 57** / 63 / 68	**≤ 48** / 41 / 34	
France QL / QLAC [1]	$\mathbf{D_{nT,w} + C \geq 53}$ / 56	≤ 55 / 52	
The Netherlands 5 / 4 / 3 / 2 / 1 [5]	$\mathbf{D_{nT,w} + C}$ ≥ 42 / 47 / 52 / 57/ 62	$\mathbf{L'_{nT,w} + C_i}$ ≤ 63 / 58 / 53 / 48 / 43	See note (4)
Lithuania E / D / C / B / A [8]	≥ 48 / 52 / **55** / *58* / 63** (5)	≤ 60 / 58 / **53** / *48* / 43**	See note (3)

Notes

(1) The full sets of criteria are found in the references.
XX: Legal minimum requirements are indicated with **bold**. More information about the legal requirements is found in the Tables 1 and 2.
*XX**: Numbers in *Italic* and marked with a "*****" include the spectrum adaptation terms $C_{50\text{-}3150}$ or $C_{i,50\text{-}2500}$ as defined in EN ISO 717-1 and 717-2, respectively. For numbers marked with a "(*)" the standard only recommends that $C_{50\text{-}3150}$ and $C_{i,50\text{-}2500}$ are included in the criteria applied.

(2) Horizontal, requirement for vertical is 1 dB higher.

(3) The weaker class D (and the Lithuanian Class E) is intended for specification of requirements for renovation of older housing. Concerning legal minimum requirements the Swedish and Norwegian building codes refer to class C in [3] and [4], respectively. Class C in the Danish standard [6] corresponds to the present requirements for terraced housing, but there is no link between the building code and the standard.

(4) New housing should fulfil at least class 3, preferably 2. The classes 5 and 4 are intended for renovation purposes.

(5) The standard allows $D_{nT,w}$ as an alternative to R'_w (same criteria).

References *Note: The reference numbers in this Table are not consistent with the reference numbers in the end of the paper.*

[1] Guide Qualitel (2000). Note: The first edition was published in 1993.
[2] VDI 4100 (1994).
[3] SS 25267 (2004). Note: Third edition. The first edition was published in 1996, the second edition in 1998.
[4] NS 8175 (1997). Note: Under revision. New version in 2004?
[5] NEN 1070 (1999).
[6] DS 490 (2001).
[7] IST 45 (2003).
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Table 4: *Main criteria in European schemes/proposals for sound classification of dwelllings.*

Considering the classification schemes in Europe there are several discrepancies:

- Concepts used for description of sound insulation and noise criteria
- Number of quality classes and intervals between classes
- Use of low-frequency spectrum adaptation terms
- Sound insulation internally in dwellings
- Common or separate quality levels for multi-storey and terraced housing
- Balance between criteria for airborne and impact sound insulation
- Relation to legal requirements

5 CONCLUSIONS

After approx. 50 years with almost no changes in building acoustic requirements in Europe, there is a trend towards stricter requirements, although the process is slow. During the last decade voluntary classification schemes describing different levels of acoustic comfort have been introduced in 8 countries in Europe, thus covering the need to define different quality levels.

A comparison between 24 European countries of the lega1 requirements for sound insulation between dwellings reveals significant differences concerning concepts as well as levels, and the requirements for facades differ even more. None of the voluntary classification schemes are identical.

The findings do not reflect a harmonized Europe. In the future, efforts should be made to increase the harmonization of concepts (not necessarily levels), and the requirements for facades should be based on the harmonized environmental noise indicators L_{den} and L_{night} (see [13]) for description of annoyance and sleep disturbance, respectively.

In order to gather information and share experience more systematically, a working group, EAA TC-RBA WG4 [14], has been established. In the future, this working group could advise on how to harmonize the use of concepts for sound insulation.

More noise sources (incl. neighbours' activities) and an increased demand for high quality and comfort together with a trend towards light-weight constructions are contradictory and call for optimizing building design using acoustic simulation models, see [24].

The benefits of a harmonization include facilitating the exchange of information and experience and development of design tools. Based on the experience, legal requirements and classification criteria might be adjusted and optimized.

6 ACKNOWLEDGEMENTS

The author is grateful to all the people who provided information about national sound insulation requirements and classification schemes. I hope that the data have been correctly understood and described. Any corrections or updates of information will be appreciated.

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