Sound insulation of dwellings - Legal requirements in Europe and subjective evaluation of acoustical comfort

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Introduction

The paper presents an overview of the main characteristics of the legal sound insulation requirements in several European countries and a review of investigations related to the subjective and/or objective evaluation. Based on the analysis of several investigations in the field and by laboratory simulations it is suggested how to estimate the degree of satisfaction corresponding to a specific requirement for sound insulation. The findings can also be used as a guide to specify acoustic requirements for dwellings in the future.

Acoustical comfort & willingness to pay

Acoustical comfort is a concept that can be characterised by absence of unwanted sound and 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.

In 1995 an investigation was made in Sweden in order to find what level of sound insulation new dwellings should have, see [1]. 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,.

Legal sound insulation requirements in Europe

The main requirements on airborne sound insulation between dwellings in 18 European countries have been gathered and presented in Table 1. In order to facilitate a comparison between countries, all requirements have been converted into equivalent values of R'_w. For multi-storey housing the range is approximately 50-57 dB, for terraced housing approximately 50-62 dB.

Similarly, the main requirements on impact sound insulation are presented in Table 2. For multi-storey housing the equivalent values of $L'_{n,w}$ are in the range 65-43 dB, for terraced housing 65-41 dB.

The equivalent values R'_w and $L'_{n,w}$ (mean values) are presented graphically in Fig. 1 and 2, respectively.

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 Austria has probably the strictest requirements in the world.

Legal sound insulation requirements have existed and remained essentially the same for approx. 50 years, but it should be noted that during the last few years several countries have implemented or proposed stricter requirements, cf Tables 1 - 2 and eg [3], [4].

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, eg due to the neighbours' music and footfall noise. Thus, a growing need to include the low frequency sound insulation has been recognised. As a consequence the revised standard, EN ISO 717:1996 [5],. for rating of sound insulation open 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. Examples of application are the Swedish requirements, see Table 1 and 2 or [6], class C.

A comparison of sound insulation requirements in different countries reveals significant differences:

Airborne sound insulation

8 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

5 concepts + variants/recommendations
For multi-storey housing variation 19 dB in equivalent $L'_{n,w}$
For terraced housing variation 21 dB in equivalent $L'_{n,w}$
The strictest requirements are found in Austria

The most recent version of the standard EN ISO 717 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, there is a directive from 2002, see [7], defining 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 [8], has been established recently (2002) 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 harmonise the use of concepts for sound insulation.

While legal sound insulation requirements for dwellings have existed for approx. 50 years, voluntary schemes describing classes of acoustic quality, eg [9], have been introduced during the last decade:

Country	*Classes*	*Year*
Denmark	D / C / B / A	2001
Norway	D / C / B / A	1997
Sweden	D / C / B / A	1996/1998
Iceland (draft)	D / C / B / A	2003?
Germany - VDI	I / II / III	1994
Germany - E DIN	I / II / III	2002
France	QL / QLAC	1993/1995/2000
Netherlands	5 / 4 / 3 / 2 / 1	1999
Estonia (draft)	D / C / B / A	2003?

There are significant discrepancies between the European schemes, among these descriptors, number of quality classes, intervals and levels, common or separate classes for multi-storey housing and terraced housing. In some sound classification schemes the extended frequency range down to 50 Hz is taken into use, eg in DK.

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 eg Norway and Sweden they are strongly "integrated", implying that the building code refers to a specific class in the classification standard rather than describing the requirements, and at the same time drawing attention to the fact that legislative requirements are minimum requirements.

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Main requirements in 18 European countries 2002

Country with indication of concept for formulation of requirements		**Multi-storey housing** Req. [dB]	Eq.[1] R'_w [dB]	**Terraced housing** Req. [dB]	Eq.[1] R'_w dB]
Denmark	R'_w	≥ 52[4]	52[4]	≥ 55	55
Norway	R'_w[6]	≥ 55[6]	55[6]	≥ 55[6]	55[6]
Sweden	$R'_w + C_{50\text{-}3150}$	≥ 52	~ 54[7]	≥ 52	~ 54[7]
Finland	R'_w	≥ 55	55	≥ 55	55
Iceland	R'_w[2]	≥ 52[3]	~ 52[3]	≥ 55	~ 55
Germany	R'_w	≥ 53[4]	53	≥ 57	57
UK[10]	$D_{nT,w}$	≥ 52[5]	~ 51-54	≥ 52	~ 51-54
France	$D_{nT,w} + C$	≥ 53	~ 53-56	≥ 53	~ 53-56
Austria	$D_{nT,w}$	≥ 55	~ 54-57	≥ 60	~ 59-62
Netherlands	$I_{lu;k}$	≥ 0	~ 55	≥ 0	~ 55
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[4]	~ 51	≥ 52	~ 53
Slovakia	R'_w	≥ 52	52	≥ 52	52
Estonia	R'_w	≥ 55	55	≥ 55	55
Latvia[9]	R'_w	≥ 54	54	≥ 54	54
Russia	I_b	≥ 50	52	(8)	(8)

Table 1: Overview airborne sound insulation rerequirements in 18 European countries.

Notes

(1) The equivalent minimum values of R'w are estimated according to the guidelines in [2], except the conversions of $I_{lu;k}$ and I_b.
(2) The maximum unfavourable deviation from the reference curve shall be limited to 8 dB.
(3) 55 dB recommended.
(4) Horizontal, requirement for vertical is 1 dB higher.
(5) Horizontal, requirement for vertical is 1 dB lower.
(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 for terraced housing. Probably the requirements for multi-storey housing are used.
(9) Proposed requirements
(10) New requirements from July 2003: $D_{nT,w} + C_{tr} \geq 45$ dB.

Impact sound insulation between dwellings Dec. 2002
Main requirements in 18 European countries 2002

Country with indication of concept for formulation of requirements		**Multi-storey housing** Req. [dB]	Eq.[1] $L'_{n,w}$ [dB]	**Terraced housing** Req. [dB]	Eq.[1] $L'_{n,w}$ [dB]
Denmark	$L'_{n,w}$	≤ 58	58	≤ 53	53
Norway	$L'_{n,w}$[2]	≤ 53[2]	53[2]	≤ 53[2]	53[2]
Sweden	$L'_{n,w} + C_{i,50\text{-}2500}$	≤ 58[3]	~ 58[5]	≤ 58[3]	~ 58[5]
Finland	$L'_{n,w}$	≤ 53	53	≤ 53	53
Iceland	$L'_{n,w}$[2]	≤ 58[4]	58[4]	≤ 53	53[4]
Germany	$L'_{n,w}$	≤ 53	53	≤ 48	48
UK	$L'_{nT,w}$	≤ 62	~ 64-57		
France	$L'_{nT,w}$	≤ 58	~ 60-53	≤ 58	~ 60-53
Austria	$L'_{nT,w}$	≤ 48	~ 50-43	≤ 46	~ 48-41
Netherlands[8]	I_{co}	≥ +5	~ 61-54	≥ +5	~ 61-54
Italy	$L'_{n,w}$	≤ 63	63	≤ 63	63
Spain[7]	$L'_{n,w}$	≤ 65	65	≤ 65	65
Portugal	$L'_{n,w}$	≤ 60	60	≤ 60	60
Poland	$L'_{n,w}$	≤ 58	58	≤ 53	53
Slovakia	$L'_{n,w}$	≤ 58	58	≤ 58	58
Estonia	$L'_{n,w}$	≤ 53	53	≤ 53	53
Latvia[7]	$L'_{n,w}$	≤ 58	58	≤ 58	58
Russia	I_y	≤ 67	60	(6)	(6)

Table 2: Overview impact sound insulation requirements in 18 European countries.

Notes

(1) The equivalent maximum values of $L'_{n,w}$ are estimated according to the guidelines in [2], except the conversions of I_{co} and I_y.
(2) It is recommended that the same criteria are fulfilled by $L'_{n,w} + C_{i,50\text{-}2500}$.
(3) The same criteria shall also be fulfilled by $L'_{n,w}$.
(4) 53 dB recommended.
(5) Assuming heavy constructions, stricter requirement for light-weight constructions
(6) No requirements for terraced housing. Probably the requirements for multi-storey housing are used.
(7) Proposed requirements.
(8) The indicated requirements valid from January 2003.

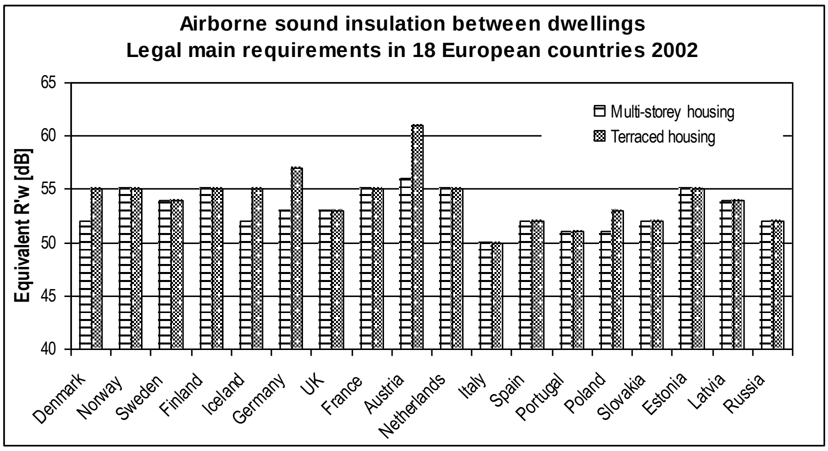

Fig. 1: Overview airborne sound insulation requirements between dwellings. Graphical presentation of equivalent values of R'$_w$ from Table 1. In case of the equivalent R'$_w$ being an interval, the average value has been indicated.

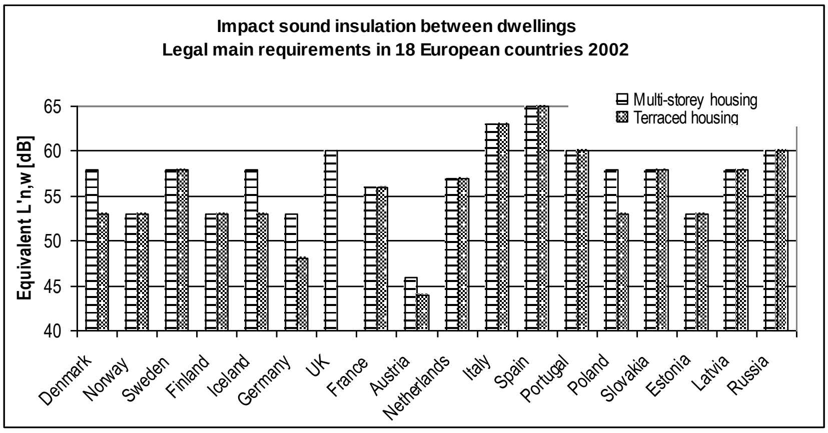

Fig. 2: Overview impact sound insulation requirements between dwellings. Graphical presentation of equivalent values of L'$_{n,w}$ from Table 2. In case of the equivalent L'$_{n,w}$ being an interval, the average value has been indicated.

Low frequency sound insulation

In a Nordic project, see [10], it was decided to investigate how the new C-corrections would behave for different building constructions. Measurement results in the extended frequency range down to 50 Hz were collected from typical newer housing in the Nordic countries. For airborne sound insulation the main results are summarised in Table 3. For constructions of concrete and porous concrete the average value of the C-correction is -2 dB, whereas the lightweight constructions from wood or gypsum board are evaluated stricter, but also with a wider range of values.

Type of construction	Number of measurements	$C_{50\text{-}5000}$		
		Average	Minimum	Maximum
Concrete	9	-2.0 dB	-3 dB	-1 dB
Porous concrete	23	-2.0 dB	-4 dB	-1 dB
Wood, hardboard	15	-3.5 dB	-6 dB	-1 dB
Gypsum board	19	-5.3 dB	-14 dB	-2 dB

Table 3: The spectrum adaptation terms for airborne sound insulation as found in field measurements from the Nordic countries, [10].

A similar investigation was performed for impact noise, see Table 4. Only data from vertical transmission were used. The construc tions can be divided into three groups called heavy, medium and light. Heavy constructions include concrete and hollow concrete. Medium-weight constructions include Leca-concrete, EW-slab (a combination of concrete and wood). Light constructions are from wood, hardboard, and gypsum board. The average values show a difference of around 6 dB between the heavy and the light categories. However, the spread is very large, from –11 dB to +13 dB.

Type of construction	Number of measurements	$C_{i,\ 50\text{-}2500}$		
		Average	Minimum	Maximum
Heavy	27	-3.2 dB	-11 dB	1 dB
Medium	53	1.5 dB	-2 dB	5 dB
Light	62	2.4 dB	-2 dB	13 dB

Table 4: The spectrum adaptation terms for impact noise as found in field measurements from the Nordic countries, [10].

Investigations of subjective and/or objective evaluation of sound insulation

Information has been gathered from social surveys, see eg [3], and from laboratory experiments about the dose-response functions for noise annoyance with relation to acoustical comfort, see [11], [12]. For all the relevant sources of noise in dwellings it is found that the dose-response relationship has a slope of approximately 4% per dB on the middle part of the regression line, i.e. between 20% and 80% annoyed or satisfied persons.

Noise from neighbours - Laboratory experiment

At the Technical University of Denmark a laboratory experiment has been carried out to investigate systematically the influence of low-frequency content in noise from neighbours [13]. The experiment was carried out in a listening room fulfilling IEC Recommendation 268-13. Three sound signals were used: Music from a neighbouring room, footfall noise from a male walker in the room above and from two children running in the room above.

The frequency spectrum of each of the three sound signals was modified in order to simulate five different types of building constructions. For airborne sound the slope of the spectrum between 50 Hz and 160 Hz was varied in order to simulate the sound transmission though different constructions ranging from light to heavy. Above 160 Hz the spectrum was kept constant. For impact noise a similar procedure was used, but only the slope of the spectrum between 50 Hz and 125 Hz was varied. The sound examples were presented to 25 test persons through loudspeakers. Some of the main results are shown in Table 5 and 6.

Type of construction	R'_w	$R'_w + C_{50\text{-}3150}$	$L_{A,eq}$ Music	% annoyed Music
Light	56 dB	49 dB	48,0 dB	98%
Light – medium	56 dB	53 dB	42,6 dB	90%
Medium	57 dB	55 dB	37,3 dB	80%
Medium – heavy	57 dB	56 dB	35,7 dB	83%
Heavy	57 dB	56 dB	35,1 dB	83%

Table 5: Results of laboratory experiment with airborne sound and simulated constructions with varying sound insulation below 160 Hz, [13].

Type of construction	$L'_{n,w}$	$L'_{n,w} + C_{i,\,50\text{-}2500}$	$L_{A,eq}$		% annoyed	
			Walker	Children	Walker	Children
Light	55 dB	62 dB	38,9 dB	40,6 dB	71%	81%
Light – med.	55 dB	58 dB	32,2 dB	34,9 dB	51%	78%
Medium	55 dB	56 dB	26,7 dB	29,9 dB	36%	47%
Med. – heavy	55 dB	55 dB	24,8 dB	27,6 dB	28%	51%
Heavy	54 dB	54 dB	23,6 dB	25,4 dB	20%	47%

Table 6: Results of laboratory experiment with impact sound and simulated constructions with different sound insulation below 125 Hz, [13].

Based on the results of this investigation it is concluded that the use of the spectrum adaptation terms down to 50 Hz imply a significantly improved correlation between subjective and objective evaluation of sound insulation for airborne as well as impact sound insulation between dwellings. Other researchers have come to a similar conclusion; eg [14], who compared objective and subjective evaluation of impact noise from about 190 floors.

However, it is only the performance of the two categories light and light-medium that differs significantly from the performance of the heavier constructions. For the heavy, medium-heavy and medium constructions the low frequencies appear to be a minor problem.

Design criteria for acoustical comfort

From the previously reported investigations of surveys on noise from neighbours, [3], [11], [12], it is possible to derive approximate relationships between the acoustic conditions and the expected percentage of people finding the conditions good or satisfactory, see Table 7. It is seen that the current Swedish requirements on airborne and impact sound insulation can be estimated to give satisfactory conditions for approximately 40%. However, these are the minimum requirements, and Sweden and many other countries have introduced a system of sound classification, and the higher sound classes could typically correspond to 60% and 80% satisfied people.

% finding conditions satisfactory	Airborne sound insulation $R'_w + C_{50\text{-}3150}$	Impact sound pressure level $L'_{n,w} + C_{i,\,50\text{-}2500}$	Noise from heating or air condition $L_{A,eq}$
20 %	48 dB	63 dB	40 dB
40 %	53 dB	58 dB	35 dB
60 %	58 dB	53 dB	30 dB
80 %	63 dB	48 dB	25 dB

Table 7: Relation between acoustic design criteria for dwellings and the expected percentage of people finding conditions satisfactory.

The different classes in sound classification schemes are intended to reflect different levels of acoustics comfort, cf eg VDI 4100 [9] or other classification schemes.

Conclusion

After approx. 50 years with almost no changes in building acoustic requirements in Europe, there seems to be a trend towards stricter requirements. During the last decade voluntary classification schemes describing different levels of acoustic comfort have been introduced in 6 countries - and proposed in 2 more countries.

A comparison between 18 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 harmonised Europe. In the future, efforts should be made to increase the harmonisation of concepts (not necessarily levels), and the requirements for facades should be based on the harmonised environmental noise indicators L_{den} and L_{night} for description of annoyance and sleep disturbance, respectively.

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