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SBUF 12311: Optimerade och harmoniserade ljudkrav på flerbostadshus

Delrapport D. Internationell litteraturöversikt

Innehållsförteckning

Projektresultat och mål

- Se delrapport A

Summary and conclusions, relevant for SS 25267/BBR

A brief overview of international publications has been undertaken to search for a global impression on the performance of the Swedish sound requirements compared to the international requirements.

From the papers cited below, there are some apparent similarities in the socio-acoustic research results that support suggested criteria in sound classification schemes as well as to legislation on the building performance. But the investigations are made in different manners and there are many reasons to why results from other countries may not be applicable to Swedish classification on sound in residential buildings.

With a harmonized template for enquiries (as proposed in our report part C), it will be easier to derive comparable results from surveys among habitants in residential buildings. To conclude, there is still a need to make more investigations to make recommendations on the basis of international comparisons.

In multi-family residential houses, sounds from neighbours and equipment are probably not possible to avoid completely. TNO (The Netherlands) reported some figures that are quite typical: ” … the scale and severity of noise annoyance from neighbouring dwellings…show that 10% had had serious annoyance from these sounds and 32% to some degree. Almost half of the respondents (47%) said they could hear daily noise from neighbouring dwellings.” What turns an audible sound into disturbing noise is a complicated issue, but the attitude to the sound plays an important role, e.g. whether the sound is perceived as avoidable (unnecessary).

TNO also reported a very useful result in the context of sound classification schemes and legislation: The annoyance from neighbours noise is less for ’normal, unavoidable sounds’ and higher for ’avoidable noisy events’. Habitants are indeed capable of judging whether the sound insulation and sound from equipment is reasonable and also to judge whether the problem is related to the building construction or the behaviour of the neighbour. Do-it-your-self-work, playing loud music, shouting, hard closing of doors etcetera can be avoided most of the time. When they cannot be avoided, good planning, information and communication between neighbours reduce annoyance from the sounds, e.g. when refurbishments or parties take place. This also implies, *we do not need to insulate for sound events that occur rarely and can be explained by abuse, but we shall insulate buildings for everyday sounds that cannot be avoided* because habitants need a certain freedom to talk, listen to music etcetera.

Rasmussen (Denmark) proposes new requirements, for standard and increased requirements:

”Standard requirement”	”Increased requirement”
Airborne sound insulation between dwellings: $D_{nT,w} + C_{50–3150} \geq 55$ dB	Airborne sound insulation between dwellings: $D_{nT,w} + C_{50–3150} \geq 60$ dB
Impact sound insulation between dwellings: $L'_{nT,w} + C_{I,50–2500} \leq 50$ dB	Impact sound insulation between dwellings: $L'_{nT,w} + C_{I,50–2500} \leq 45$ dB

Gerretsen (The Netherlands) proposed lower values for the airborne insulation in three classes, minimum 52, improved 57 and very high 62 dB, i.e. 3 dB lower than in the table above but close to the Swedish values. Lang (Austria) also proposed lower values, 54-58-63 dB, with an extra 'music class' 68 dB. For impact sound Lang proposes 50-45-40 dB, i.e. the same as in the table, that are considerably stricter than the Swedish values.

Kurz and Fischer (Germany) observed that R'w 54-56 dB would be needed for walls and 57-59 dB for floors to avoid more than 15% of complaints. Considering the C-terms, these values correspond reasonably well to Rasmussens table. For impact sound, L'n,w 45 dB is suggested, that actually may correspond to about the same as the table given the floating floor constructions with large Ci-terms being commonly used in Germany.

Bradley (Canada) suggests

> " An effective STC of 55 is therefore recommended as a realistic goal and STC 60 as a more ideal goal for party wall sound insulation."

STC 55-60 roughly equals $R'_w + C_{50\text{-}3150}$ 53-58 dB for heavy constructions, so these recommendations are somewhat lower than Rasmussens values but agree well with the Swedish values.

The German DEGA-guideline recommends for classes D-less/C-regular/B-improved, that also may be close to the table when converted into its single numbers:

- R'w 53/57/62 dB for walls, R'w 54/57/62 dB for floors
- L'n,w 53/46/40 dB for floors, L'n,w 53/46/40 dB for stairs etc

Neubauer (Germany) recommends

> " *DnT,w + C ≥ 58* dB for reasonable acoustical comfort in dwellings".

A Scottish study concludes that for both party walls and floors, it seems that the required sound insulation 53 dB is sufficient for satisfactory performance, but good performance would require 3 dB higher insulation (56 dB). These values are lower than the table since the C-term is usually -2 dB or less.

For noise from building service equipment, the habitants complain about the use of the equipment (e.g. WC) rather than the normal operation (flushing). The main finding of Kurze and Fischer is that L_{pAFmax} 32 dB corresponds to 15% dissatisfied habitants. The German DEGA guideline recommends (B/C/D) $L_{pAFmax,n}$ 30/25/20 for water installations and use of WC. To avoid excessive low frequency noise, L_C-L_A ≤ 20 dB is adviced.

From the results above, the following criteria may be compared with the Swedish enquiries and current legislation:

"Standard requirement", class C	"Increased requirement", class B
Airborne sound insulation between dwellings: $D_{nT,w} + C_{50–3150} \geq 53$ dB ($\approx D_{nT,w} \geq 55$ dB)*	Airborne sound insulation between dwellings: $D_{nT,w} + C_{50–3150} \geq 57$ dB ($\approx D_{nT,w} \geq 59$ dB)*
Impact sound insulation between dwellings: $L'_{nT,w} + C_{I,50–2500} \leq 56$ dB ($\approx L'_{nT,w} \leq 56$ dB)*	Impact sound insulation between dwellings: $L'_{nT,w} + C_{I,50–2500} \leq 52$ dB ($\approx L'_{nT,w} + C_{I,50–2500} \leq 52$ dB)*

*) for heavy constructions where Ci50-2500 is close to zero. Room sizes determine the LnT,w/Ln,w difference.

In the Swedish standard, a 2 dB deviation is accepted if the average measured value fulfills the requirement. In other standards/legislation, the given value is the lower limit and no exceptions should be accepted – in principle. It is important to address design goals, inevitable uncertainties and acceptable deviations within a sound class.

For airborne sound insulation, the Swedish requirements seem to be in line with the research results discussed above. However, for impact sound insulation the Swedish requirements seem to be less strict than the proposed values. This needs to be discussed further, e.g. in the COST Action network.

One important issue to add to all standards is the extraneous sources of noise, mostly structure borne sound from cupboards, switches, do-it-yourself noises etcetera.

International publications

Reasons for building legislation on acoustic performance

In two recent conference papers, Rasmussen[1] gives overviews that refer to broad surveys made in Europe. Their results support the importance of appropriate noise protection of dwellings. The first paper from a conference in Ljubljana 2010 illustrates this statement:

The relevance of the sound insulation issue is illustrated in Figure 1 (ref. [3]) showing the amount of serious noise annoyance in national surveys in three EU countries, representing about 1/3 of the total EU population. In spite of uncertainties due to different methodologies (including questionnaires) applied for the surveys, the author of [3] concluded that the neighbour noise problem in Europe is significant. In [4], results from different social surveys are included, and the shortcomings due to inconsistent questionnaires in different countries are described. Neighbour noise has been addressed in a large pan-European LARES study (Large Analysis and Review of European housing and health Status) coordinated by WHO/Europe. The WHO LARES study included eight European cities and the purpose was to evaluate the health impact of housing conditions. Results are found at the WHO website [2] (some quotes and more detailed references are found in [6] and [16]).

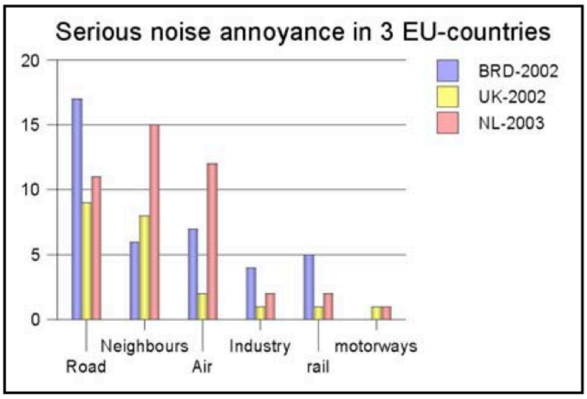

Figure 1. Sources of serious noise annoyance (% of inhabitants) in three EU countries.
Ref: Martin van den Berg, 2004, [3].

When ranking annoyance from different noise sources, road traffic noise is the most dominant source, followed by neighbour noise. Based on statistics about populations [5] and findings from noise annoyance surveys (see eg Figure 1 or [4]), it seems that more than 50 million Europeans are exposed to neighbour noise causing adverse effects on quality of life.

[3] Van den Berg, M. *"Neighbour Noise: A rational Approach"*, pp. 151-154 in Proceedings of the 2nd WHO
International Housing and Health Symposium. WHO, Bonn (2004).
[4] J Lang, R Pierrard, W Schönbäck, *"Sound Insulation in Housing Construction"*, TU Wien, Vienna, July 2006. A summary is found in J Lang (2007), "Schallschutz im Wohnungsbau". WKSB 59/2007.
[5] http://www.europa.eu [6] B Rasmussen, *"Sound insulation between dwellings – Requirements in building regulations in Europe"*.

Applied Acoustics, 2010, 71(4), 373-385. http://dx.doi.org/10.1016/j.apacoust.2009.08.011 [7] B Rasmussen & JH Rindel *"Sound insulation between dwellings – Descriptors in building regulations in Europe"*. Applied Acoustics, 2010, 71(3), 171-180. http://dx.doi.org/10.1016/j.apacoust.2009.05.002 [8]
B Rasmussen, *"Sound insulation of residential housing - Building codes and classification schemes in Europe"*. Chapter 114 in Handbook of Noise and Vibration Control. Wiley & Son, USA, 2007. [9]
B Rasmussen, *"Sound classification of dwellings – Comparison of schemes in Europe"*, NAG/DAGA 2009,
Rotterdam, Netherlands. Paper ID 453.
[10] COST Action TU0901 *"Integrating and Harmonizing Sound Insulation Aspects in Sustainable Urban Housing Constructions"*, 2009-2013, www.cost.eu/index.php?id=240&action_number=tu0901 (public information at COST website) or http://www.costtu0901.eu/ (Action website).

In another paper from 2010, Rasmussen cites[2] a conclusion of the LARES study made by WHO:

> " 5.2 Is sound insulation in housing of any interest to society?
> Public health is of interest to society for economic reasons. Furthermore, to keep stability and avoid conflicts between neighbours, it is of public interest that the inhabitants are satisfied with the housing conditions. Otherwise, some people might move to more attractive locations, leaving behind those with fewer resources and thus influencing the population balance. Regulatory sound insulation requirements primarily aim at ensuring a reasonable sound insulation in new housing and should also be applied as far as possible, when rebuilding or renovating housing. For existing housing in general, other initiatives must be applied to increase sound insulation, where needed. It is important to be able to define "reasonable sound insulation" in a way that enables objective criteria to be set in the legislation, so the performance as perceived by the occupants correlates well with the objective performance, cf. [10].
> 5.3 Homes for the future?
> In the WHO LARES survey about European housing [4], it is concluded: ''Looking back in time, the housing stock development does not match the social changes and the gain in life expectancy of the last decades. Today, people spend years and years in dwellings that have not been designed to meet the needs and lifestyles of the moment as well as the needs and lifestyles of the future". Neighbour noise is identified as a health problem, and reduction of noise exposure in the home is included in the proposed objectives for a policy.
> In the conclusions in [4], housing is defined as follows: ''Housing is the conjunction of dwelling, home, immediate environment and community. The role of public health is to provide circumstances under which people can be healthy"."

Further references are made in

[3] (a) Proceedings of the 2nd WHO International Housing and Health Symposium. WHO, Noise and Housing Unit (NOH). WHO, Bonn (2004). http://www.euro.who.int/Document/E87878.pdf.
[3] (b) Van den Berg, M. "Neighbour Noise: A rational Approach", pp. 151-154.
[4] WHO (2007), "Large analysis and review of European housing and health status (LARES) – preliminary over- view", World Health Organization, Regional Office for Europe, Copenhagen.
http://www.euro.who.int/Document/HOH/lares_result.pdf

England, BRE (Grimwood)

Grimwood published an BRE Information paper in 2003, that summarized the results of 'The National Noise Attitude Survey' made 1991 in the UK.[3] The figure below is of interest because the requirements on airborne and impact sound insulation were lower in the UK than in many other European countries.

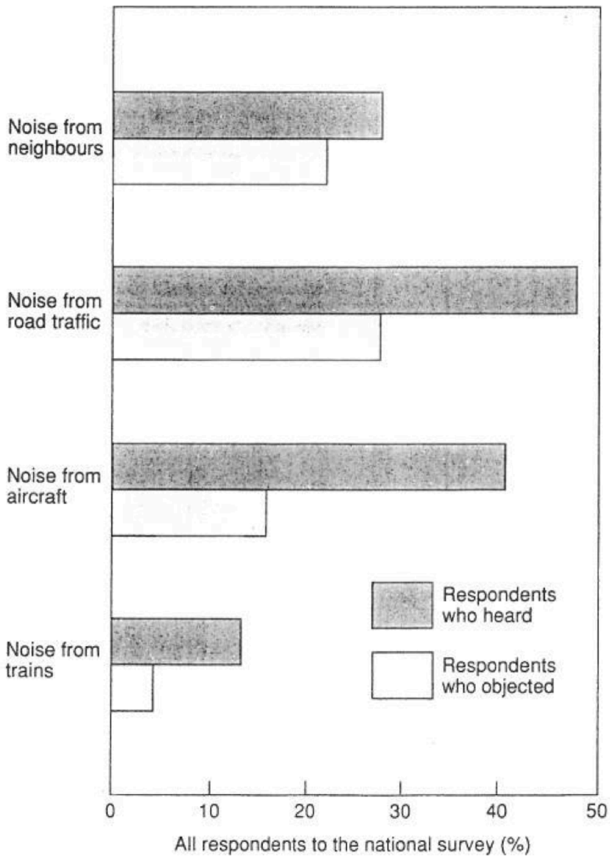

Figure 2 Percentage of respondents to the national noise attitude survey who heard and objected to the main categories of noise

The author also found some interesting aspects on how questions should be stated in such a survey. **Respondents tend to *under*estimate the adverse effect noise has on their lives**.

Appraisal of typical survey questions

Participants were also invited to discuss questions which appeared in previous surveys of reaction to noise. It became clear that the responses to some typical questions did not always tell the questioners what they wanted to know or what the respondent had actually felt. For example, when describing noise levels, terms such as 'satisfactory or unsatisfactory' were considered too formal, weak and detached from the way people experienced the effects of noise. Similarly, 'bother' was not a word that people used to describe the effects of noise; it tended only to be used negatively (as in 'not bothered'). The word 'annoyance' also needs to be used with caution as it has been found to have two meanings for respondents, both as a general indicator of adverse effects and also as a specific emotional reaction experienced by some people only.

Participants felt that that they could only give meaningful answers to questions which were specific about the time, place and type of noise. They also favoured questions which featured a list of the possible adverse consequences of noise, including emotional responses and interference with domestic activities. It also emerged from the discussions that many people tend to understate the adverse effects that noise has on them, even though these effects may in fact be very important to them personally.

Other papers on questionnaire design are summarized and analyzed by Andres-Gallego in a separate report to this SBUF project and to the COST TU 0901 members. In spite of what was mentioned by Grimwood, the annoyance was used as the primary factor for the COST questionnaire since it has been standardized by ISO. It is also reported by others to be perceived as very direct an uncomplicated to respond to; ”are you annoyed by this sound?”

Denmark, SBI (Rasmussen)

Rasmussen has presented an overview of existing sound classification schemes in[2].

[18] DS 490:2007, “Lydklassifikation af boliger”. (Sound classification of dwellings), Denmark.
[19] SFS 5907:2004, “Rakennusten Akustinen Luokitus“, Finland. English version “Acoustic classification of spaces in buildings” published in July 2005.
[20] IST 45:2003, “Acoustics - Classification of dwellings”, Iceland. Note: Under revision, cf. Draft IST 45:2010, “Acoustic conditions in buildings - Sound Classification of Various Types of Buildings” (publicat-ion expected in 2010).
[21] NS 8175:2008, “Lydforhold i bygninger, Lydklassifisering av ulike bygningstyper” (Sound conditions in build- ings - Sound classes for various types of buildings), Norway.
[22] SS 25267:2004, “Byggakustik – Ljudklassning av utrymmen i byggnader – Bostäder”. (Acoustics – Sound clas- sification of spaces in buildings – Dwellings). Sweden.
[23] 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.
[24] NEN 1070:1999, “Geluidwering in gebouwen – Specificatie en beoordeling van de kwaliteit” (Noise control in buildings – Specification and rating of quality), The Netherlands.
[25] VDI 4100:2007, “Schallschutz von Wohnungen - Kriterium für Planung und Beurteilung" and "Noise control in dwellings – Criteria for planning and assessment". Germany.
[26] La méthode qualitel”, 2008, Association Qualitel, France. www.cerqual.fr [27] DEGA-Empfehlung 103, “Schallschutz im Wohnungsbau – Schallschutzausweiz”, DEGA, March 2009 http://dega-schallschutzausweis.de/

A summary of the descriptors used in the European classification schemes were made by Rasmussen and Rindel in a paper in Applied Acoustics.

Table 4
Overview of descriptors for evaluation of sound insulation and applications in regulatory requirements and classification schemes in Europe.

Descriptors for evaluation of sound insulation between dwellings	Applications in 24 countries$^{(a)}$ in Europe April 2008																								No. of countries			Summary$^{(b)}$	
	AT	BE	CZ	DK	EE	FI	FR	DE	HU	IS	IE	IT	LV	LT	NL	NO	PL	PT	SK	SI	ES	SE	CH	GB	BC	CS	BC + CS	BC	CS
Airborne sound insulation																													
R'_w			+	⊕	+	⊕		⊕		⊕		+	+	⊕		⊕			+	+		O			12	7	13	✓	✓
$R'_w + C$									+								+								2	0	2	✓	
$R'_w + C_{50-3150}$				O		O				O				O								⊕			1	5	5	✓	✓
$R'_w + C_{100-5000}$																									0	0	0		
$R'_w + C_{50-5000}$																O									0	1	1		✓
$D_{n,w}$																		+							1	0	1	✓	
$D_{n,w} + C$																									0	0	0		
$D_{n,w} + C_{50-3150}$																									0	0	0		
$D_{n,w} + C_{100-5000}$																									0	0	0		
$D_{n,w} + C_{50-5000}$																									0	0	0		
$D_{nT,w}$	+	+									+			⊕											4	1	4	✓	✓
$D_{nT,w} + C$							⊕								O								+		2	2	3	✓	✓
$D_{nT,w} + C_{50-3150}$														O											0	1	1		✓
$D_{nT,w} + C_{100-5000}$																					+				1	0	1	✓	
$D_{nT,w} + C_{50-5000}$																									0	0	0		
$D_{nT,w} + C_{tr}{}^{(c)}$																								+	1	0	1	✓	
$I_{lu;k}{}^{(d)}$ ($= R'_w + C - 52$ dB)															+										1	0	1	✓	
Impact sound insulation																													
$L'_{n,w}$			+	⊕	+	⊕		⊕	+	⊕		+	+	⊕		⊕	+	+	+	+		O			15	7	16	✓	✓
$L'_{n,w} + C_I$																									0	0	0		
$L'_{n,w} + C_{I,50-2500}$				O		O				O				O		O						⊕			1	6	6	✓	✓
$L'_{nT,w}$	+	+					⊕				+										+			+	6	1	6	✓	
$L'_{nT,w} + C_I$															O								+		1	1	2	✓	✓
$L'_{nT,w} + C_{I,50-2500}$																									0	0	0		
$I_{co}{}^{(d)}$ ($= 59 - L'_{nT,w} + C_I$ dB)															+										1	0	1	✓	

(a) BC = Building Code (regulatory requirements); CS = Classification scheme; + Regulatory requirements; O Classification schemes; ⊕ Both applications Countries are listed alphabetically according to country names in English and indicated using the ISO country code. The information for GB (UK) is valid for England and Wales only.
(b) Information about application in Europe (at least 1 of 24 countries).
(c) $D_{nT,w} + C_{tr}$ included due to application in England and Wales. According to ISO 717-1, C_{tr} is primarily intended for facade sound insulation).
(d) $I_{lu;k}$ and I_{co} are not ISO 717 descriptors, but are included due to application in the Netherlands. Definitions are found in NEN 5077:2006.
$I_{lu;k} = R'_w + C - 52$ dB; $I_{co} = 59 - (L'_{nT,w} + C_I)$ dB $\approx 70 - L'_{nT,w}$ dB for bare concrete floors or $I_{co} \approx 59 - L'_{nT,w}$ dB for other floors like wooden floors, floating floors and floors with soft coverings.

The levels of each descriptor are summarized by Rasmussen in a joint paper in Applied Acoustics:[4]

"In 2008 a comparative study investigating the legal requirements for sound insulation between dwellings was carried out. This paper is a result of that study and describes and discusses the main requirements for airborne and impact sound insulation in 24 countries in Europe. The comparison shows considerable differences in terms of descriptors, frequency range and level of requirements."

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Table 2
Airborne sound insulation between dwellings – Main requirements in 24 European countries.[a,b]

Country	Descriptor[c]	Multi-storey housing Req. (dB)	Row housing Req. (dB)
Austria	$D_{nT,w}$	⩾55	⩾60
Belgium	$D_{nT,w}$	⩾54	⩾58
Czech Rep.	R'_w	⩾52	⩾57
Denmark	R'_w	⩾55	⩾55
Estonia	R'_w	⩾55	⩾55
Finland	R'_w	⩾55	⩾55
France	$D_{nT,w} + C$	⩾53	⩾53
Germany[i]	R'_w	⩾53[g]	⩾57
Hungary	$R'_w + C$	⩾51	⩾56
Iceland	R'_w[e]	⩾52[h]	⩾55
Ireland	$D_{nT,w}$	⩾53[g]	⩾53
Italy	R'_w	⩾50	⩾50
Latvia	R'_w	⩾54	⩾54
Lithuania	$D_{nT,w}$ or R'_w	⩾55	⩾55
Netherlands	$I_{lu;k}$[d]	⩾0	⩾0
Norway	R'_w[f]	⩾55[f]	⩾55[f]
Poland	$R'_w + C$	⩾50[g]	⩾52[h]
Portugal[i]	$D_{n,w}$	⩾50	⩾50
Slovakia	R'_w	⩾52	⩾52
Slovenia	R'_w	⩾52	⩾52
Spain	$D_{nT,w} + C_{100-5000}$	⩾50	⩾50
Sweden	$R'_w + C_{50-3150}$	⩾53	⩾53
Switzerland	$D_{nT,w} + C$	⩾52[j]	⩾55
UK[k]	$D_{nT,w} + C_{tr}$	⩾45	⩾45

Notes:
[a] Study carried out in 2008. Data verified April 2008.
[b] Overview information only. Detailed requirements and conditions are found in the building codes.
[c] No generally applicable conversion between the different descriptors exists, as the relations depend on characteristics of rooms and constructions. Exact conversion can only be made in every specific case.
[d] $I_{lu;k} = R'_w + C - 52$ dB. Ref. [29].
[e] In addition to the rating procedure described in ISO 717, the Icelandic building regulations prescribe maximum 8 dB unfavourable deviation.
[f] It is recommended that the same criteria are fulfilled by $R'_w + C_{50-5000}$.
[g] Horizontal, requirement for vertical is 1 dB higher (Germany and Poland)/ lower (Ireland).
[h] 55 dB recommended.
[i] Under revision, use of $D_{nT,w}$ has been proposed.
[j] Flats for rent. If owned by occupants, the criterion is the same as for row housing.
[k] England and Wales only. Scotland and Northern Ireland use different descriptors and performance levels.

Table 3
Impact sound insulation between dwellings – Main requirements in 24 European countries.[a,b]

Country	Descriptor[c]	Multi-storey housing Req. (dB)	Row housing Req. (dB)
Austria	$L'_{nT,w}$	⩽48	⩽43
Belgium	$L'_{nT,w}$	⩽58[g]	⩽50
Czech Rep.	$L'_{n,w}$	⩽58	⩽53
Denmark	$L'_{n,w}$	⩽53	⩽53
Estonia	$L'_{n,w}$	⩽53	⩽53
Finland	$L'_{n,w}$[f]	⩽53[f]	⩽53[f]
France	$L'_{nT,w}$	⩽58	⩽58
Germany[j]	$L'_{n,w}$	⩽53	⩽48
Hungary	$L'_{n,w}$	⩽55	⩽45
Iceland	$L'_{n,w}$[e]	⩽58[h]	⩽53
Ireland	$L'_{nT,w}$	⩽62	None
Italy	$L'_{n,w}$	⩽63	⩽63
Latvia	$L'_{n,w}$	⩽54	⩽54
Lithuania	$L'_{n,w}$	⩽53	⩽53
Netherlands	I_{co}[d]	⩾ +5	⩾ +5
Norway	$L'_{n,w}$[f]	⩽53[f]	⩽53[f]
Poland	$L'_{n,w}$	⩽58	⩽53
Portugal[j]	$L'_{n,w}$	⩽60	⩽60
Slovakia	$L'_{n,w}$	⩽58	⩽58
Slovenia	$L'_{n,w}$	⩽58	⩽58
Spain	$L'_{nT,w}$	⩽65	⩽65
Sweden	$L'_{n,w} + C_{I,50-2500}$	⩽56[i]	⩽56[i]
Switzerland	$L'_{nT,w} + C_I$	⩽53[k]	⩽50
UK[l]	$L'_{nT,w}$	⩽62	None

Notes:
[a] Study carried out in 2008. Data verified April 2008.
[b] Overview information only. Detailed requirements and conditions are found in the building codes.
[c] No generally applicable conversion between the different descriptors exists, as the relations depend on characteristics of rooms and constructions. Exact conversion can only be made in every specific case.
[d] $I_{co} = 59 - (L'_{nT,w} + C_I)$ dB $\approx 70 - L'_{nT,w}$ dB for bare concrete floors or $I_{co} \approx 59 - L'_{nT,w}$ dB for other floors like wooden floors, floating floors and floors with soft coverings. Ref. [29].
[e] In addition to the rating procedure described in ISO 717, the Icelandic building regulations prescribe maximum 8 dB unfavourable deviation.
[f] It is recommended that the same criteria are fulfilled by $L'_{n,w} + C_{I,50-2500}$.
[g] From "non-bedrooms" outside the dwelling to a bedroom ⩽ 54 dB is required.
[h] 53 dB recommended.
[i] The same criteria shall also be fulfilled by $L'_{n,w}$.
[j] Under revision, use of $L'_{nT,w}$ has been proposed.
[k] Flats for rent. If owned by occupants, the criterion is the same as for row housing.
[l] England and Wales only. Scotland and Northern Ireland use different per-

Rasmussen writes:
” It is concluded that regulatory sound insulation requirements need tightening in some countries. As a starting point for further discussion, suggestions for airborne and impact sound insulation criteria providing ‘‘standard” and ‘‘increased” comfort are given. While tightening regulations implies a growing need for exchange of information and experience, the diversity in Europe creates difficulties for efficient cooperation, and harmonization of descriptors is needed. The benefits of harmonizing descriptors include facilitating the exchange of construction data, design details and development of design tools. Based on experience, legal requirements and classification criteria could be adjusted and optimized.”

Rasmussen also proposes new requirements, for standard and increased requirements: [5]

”Standard requirement”	”Increased requirement”
Airborne sound insulation between dwellings: $D_{nT,w} + C_{50–3150} \geq 55$ dB	Airborne sound insulation between dwellings: $D_{nT,w} + C_{50–3150} \geq 60$ dB
Impact sound insulation between dwellings:	Impact sound insulation between dwellings:

$L'_{nT,w} + C_{I,50-2500} \leq 50$ dB	$L'_{nT,w} + C_{I,50-2500} \leq 45$ dB

Rasmussens summary has been updated by the members of the COST TU 0901 action, where the advantages and disadvantages were collected during 2010 and analyzed by its WG1 members in December 2010. The WG1 members are in favour of the following parameters to be applied to a common european standard:

- $D_{nTw} + C_{100-3150}$ or $D_{nTw} + C_{50-3150}$ for airborne sound insulation rather than R'_w
- $L'_{nT,w}$, $L'_{nT,w} + C_{i,50-2500}$ or $L'_{n,w} + C_{i,50-2500}$ for impact sounds rather than $L'_{n,w}$
- $D_{nTw,2m} + C_{50-3150}$ for traffic sounds rather than indoor levels L_{pAeq} or $L_{A,den}$
- L_{pAeq} and L_{pAFmax} for indoor sounds from service equipments (installations)
- Low frequency spectrum adaption terms from 50 Hz encouraged by the experts

Lang, Austria

Lang made an extensive investigation and summary of European surveys[6] and she also made some calculations on the meaning of different sound insulation descriptors in practice:

> ” In order to prove which protection against airborne sound (caused by typical activities) transmitted from the neighbouring flat is given when observing the minimum standard requirements and when improving the sound insulation, calculations were made on the sound level produced in the neighbouring flat, assuming different sound sources in the flat and different levels of sound insulation against noise from the neighbouring flat. The calculated sound level was then compared with different requirements for quietness. According to ÖNORM S 5012, the following assumptions can be made for the sound levels produced by different activities of daily living:
> Conversation (with guests, 6 persons in a 75 m3 living room of usual furnishing): Equivalent A-weighted continuous sound level: 73 dB for conversations of normal loudness 78 dB for animated conversations with laughter
> Peak level 82 dB resp. 87 dB A-weighted. Domestic music-making (ensemble of 6 instruments, 100 m3 living room of usual furnishing): Equivalent A-weighted continuous sound level 91 dB, peak level 98 dB Domestic music-making (1 violin in a 75 m3 living room of usual furnishing): Equivalent A-weighted continuous sound level 78 dB, peak level 86 dB
> The two latter sound levels also correspond to the loud music coming from HiFi systems in flats. The frequency distribution pink noise can be used for conversation and for music (sound levels identical in all one-third octave bands).

Table 1 below gives an overview of the A-weighted sound levels that result in the receiving room from the above sound levels in the source room with a different standardized sound level difference.”

Table 1: Sound level in the receiving room depending on sound insulation and sound level in the source room

A-weighted sound level in the source room (dB)	A-weighted sound level in the receiving room (dB) at a sound insulation of D_{nTw}			
	55 dB	60 dB	65 dB	70 dB
73	19	14	9	4
78	24	19	14	9
86	32	27	22	17
91	37	32	27	22
98	44	39	34	29

To avoid disturbances, the level should preferably be less than 20 dB in bedrooms and 25 dB in living rooms, where the background levels may be rather low. Lang summarizes this:

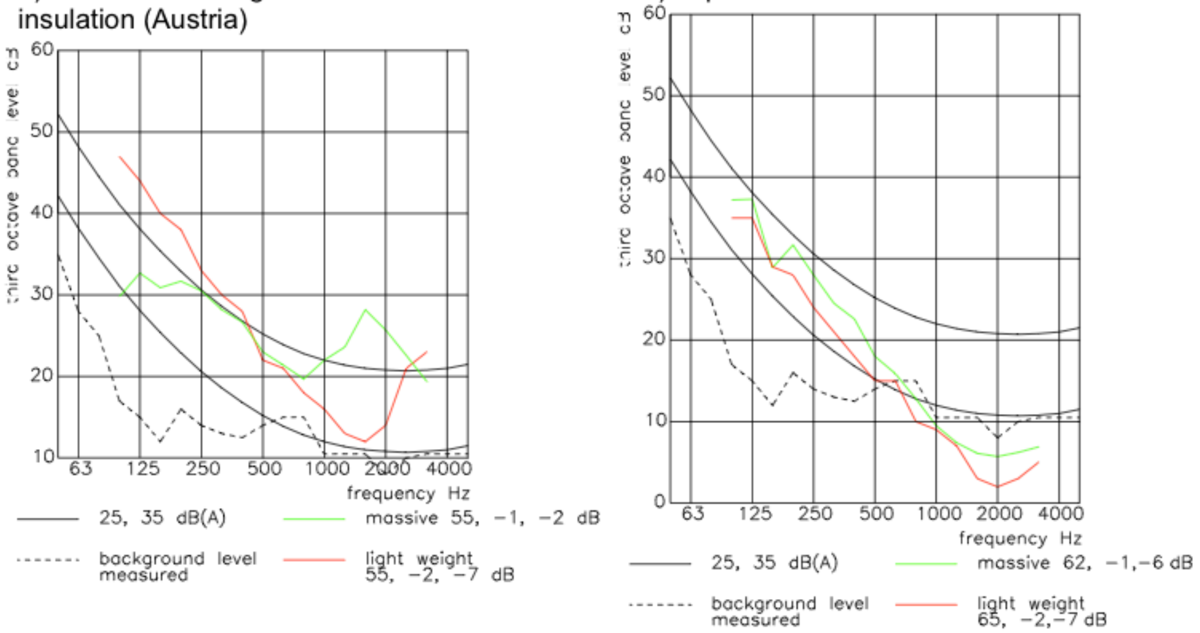
> ”A comparison of the values in Table 1 with the background noise values shows that the minimum sound insulation of DnT,w = 55 dB lowers the equivalent continuous sound level of normal conversation (which is more or less equal to playing radio/TV at a moderate volume) down to 19 dB in the neighbouring room. At a background sound level of 25 dB, this noise will not be audible whereas single peak sound levels will be audible from case to case.”

Lang also shows a more detailed calculation in third octave bands.

Figure 2: 1/3 octave band level in the neighbouring room in the presence of music or talk at 90 dB (A-weighted) in the source room and different levels of sound insulation compared to the background noise level

a) Norm-conforming minimum sound insulation (Austria)

b) Improved sound insulation



Lang concludes:

> " If one compares the above results with the minimum requirements for sound insulation in the different countries, it does not come as a surprise that quite a significant percentage of the residents in multi-family dwellings feel disturbed by neighbourly noise. It is also no wonder that in the last few years several countries worked out recommendations for improved sound insulation, in addition to the existing minimum requirements. The following paragraphs briefly present some example studies from literature on the connection between sound insulation and affectedness by neighbourly noise as well as proposals for enhanced sound insulation.

In the **Netherlands**, a comprehensive study (Gerretsen, 2001) was carried out to find a suitable measurement unit for the determination of requirements and for the description of 5 "quality classes". The unit used for describing the requirements for airborne sound insulation is $D_{nT,w}$+ C. In class III, complying with the current legal requirements, a value of $D_{nT,w}$+ C ≥ 52 dB is demanded ("sufficient", "gives protection against unbearable disturbance under normal behaviour of the occupants, bearing in mind the neighbours"). In class II, the required value is $D_{nT,w}$+ C ≥ 57 dB ("good", "giving normally a good protection against intruding sound without too many restraints on behaviour of the occupants"). Class I stipulates a value of $D_{nT,w}$+ C ≥ 62 dB (corresponding to the maximum "just reachable with practical means") (Gerretsen, 2003).

…..

To sum up, it can be said that, based on the studies conducted in many countries over the last few years, a rather clear recommendation can be derived - both with respect to a well-suited unit for describing airborne sound insulation and with respect to the required value.
The most suitable unit of description is the **standardized sound level difference with the additional spectrum adaptation term $D_{nT,w}$ + C**. It would be useful to also include the low frequencies, i.e. to apply the value $C_{50-3150}$. However, we do not yet have sufficient experience concerning the appropriate value for $C_{50-3150}$. For this reason, the below-listed values for $D_{nT,w}$ + C should be valid after a transitional period that still needs to be fixed for $D_{nT,w}$ + $C_{50-3150}$.
$D_{nT,w}$ + C ≥ 54 dB can be regarded as a **standard requirement.** This level protects only people with a normal sensitivity against noise disturbance caused by normal neighbourly activities. On the other hand, the residents themselves need to cut down their activities (children, music- making) out of consideration for their neighbours.
Classes with improved sound insulation should be defined. They can be based on the requirements specified in Switzerland: depending on the sound emission during use on the one hand, and on the noise sensitivity resp. people's need for quietness on the other hand. Furthermore, the Scandinavian classes A and B as well as the Dutch sound insulation quality classes I and II can be employed. It will thus be possible to define a class of **"Enhanced sound insulation" with $D_{nT,w}$ + C ≥ 58 dB and a "Comfort" class with $D_{nT,w}$ + C ≥ 63 dB.** In any case, a further class should be created which allows music-making in a flat without disturbing your neighbours. This class could be defined as **"Music" with $D_{nT,w}$ + $C_{50-3150}$ ≥ 68 dB**[11]**.** The sound insulation class that needs to be fulfilled by a building or individual building components must then be defined as early as in the planning process."

For impact sounds, Lang summarizes an investigation on schemes and surveys made in several countries:

" **To sum up**, the investigations carried out in many countries over the last years as well as the recommendations given for higher impact sound insulation confirm that it is essential - especially for lightweight wooden floors - to consider the low frequencies. Thus, it will also be possible to cover the subjective perception of disturbance caused by the walking noise. For this reason, the prescription of requirements for impact sound insulation in residential buildings should always be based on the unit $L'_{n,w}$ + $C_{I,50-2500}$. This hardly changes the requirement to be met by massive floors, but is important for wooden floors in order to avoid disturbance caused by the "drum sound" that residents frequently complain about. The Austrian requirement $L'_{nT,w}$ ≤ 48 dB should be extended to **$L'_{nT,w}$ + $C_{I,50-2500}$ ≤ 50 dB**. Higher requirements can be described with **$L'_{nT,w}$ + $C_{I,50-2500}$ ≤ 45 dB**, and very high requirements (**comfort class**) with **$L'_{nT,w}$ + $C_{I,50-2500}$ ≤ 40 dB**."

Her final proposal for sound insulation classes are then

Table 26: Proposed requirements for airborne and impact sound insulation in 4 sound insulation classes

Class	"Music"	"Comfort"	"Enhanced" *)	"Standard"
Airborne sound insulation between flats $D_{nT,w}$ +C (dB)	≥ 68 ($C_{50-3150}$)	≥ 63	≥ 58	≥ 54
Airborne sound insulation between the rooms within a flat (without doors), also incl. one-family houses $D_{nT,w}$ +C (dB)	≥ 48	≥ 48	≥ 45	≥ 40 **)
Impact-sound insulation between flats $L'_{nT,w} + C_{I,50-2500}$ ***) (dB)	≤ 40	≤ 40	≤ 45	≤ 50
Impact-sound insulation within a flat, also incl. one-family houses $L'_{nT,w} + C_{I,50-2500}$ ***) (dB)	≤ 45	≤ 45	≤ 50	≤ 55
*) minimum requirements for terraced houses **) if requested ***) for a transitional period $L'_{nT,w} + C_I$, values decreased by 2 dB				

Source: Lang, 2006

Later discussions with prof. Lang revealed that she included the effect of floating floors in the proposed values, having Ci50-2500 spectrum adaptation terms in the order of 5 dB or more. This means, the tabulated values could be 5 dB higher when constructions with less pronounced impact sound at low frequency are more typical. If so, the values are closer to the current Swedish requirements between flats.

Holland (RIGO and TNO)

RIGO [7]

Causes of different standards

What people find 'normal' depends on their personal circumstances and family situation, but also for example the quality of the building, or the specific sounds from the neighbors. One may be seriously hampered mainly by noise, radio, stereo and TV audio and the pets of neighbors. By plumbing and installation sounds and by do-it-yourself sound only a limited proportion of households were severely hampered. Because most noise is heard, in absolute terms - the number of people hindrance is related to neighbors being the main source of noise. The tolerance is lowest for sounds of radio, stereo and TV, followed by contact noise.

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kind of noise from neighbors	% Of the neighbors hear that sound	% Annoyed when sound is heard
plumbing and installation	56%	22%
contact/impact noise	62%	27%
stereo, radio or TV	46%	29%
do-it-yourself	55%	20%
pet (barking dogs etc)	22%	21%

Table 1. Percentage of people who hear a certain source of noise from the neighbors in the house and the percentage who are annoyed by this noise

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Besides the differences in tolerance to noise types, where one is particularly sensitive to

noise that may be avoided by the neighbors, there are differences in tolerance for households in different life stages. Families are usually more sensitive to sounds of the neighbors than two-person households. The nuisance caused by noise from neighbors in the home is greatest for families with children in apartment. Older people generally report less discomfort than younger households. It should however be considered that even within each group there are significant differences. One family is not like another.

A majority of 80% judges faint but audible sounds from radio, stereo and television in the neighbours homes only acceptable if the noise lasts between five and ten minutes. If the sound lasts longer, it gradually increases the proportion annoyed from 15% up to 60% when the sound lasts for two hours. Thus, short durations are more acceptable.

TNO [8] analyzed research work that indicated high correlation between objective sound insulation (within the building) and the habitants subjective rating of the sound conditions. This correlation is for groups of respondents and dose-categories, whereas the correlation is weak at the level of individual respondents. Using 'heavily annoyed' as measurand in surveys return slightly better correlation than 'annoyed'. A very important finding of this study is:

The annoyance is less for 'normal, unavoidable sounds', higher for avoidable noisy events:
"The risk of annoyance is largest if what in principle are avoidable "noisy" sounds are heard: special pop music, having the TV/radio/audio equipment on loud, slamming doors, walking heavily on the stairs or on floors, DIY (do it yourself) noises or speaking with raised voices or shouting. There is least chance of noise from spin-driers, washing machine or "normal" unavoidable day-to-day noises: the shower and/or bath, "normal" talking and "normal" walking on floors or stairs."

Habitants then judge the building constructions to be unsatisfactory, whereas the unavoidable sounds are distinguished and referred to the neighbours, not the building. In other words, habitants do not expect the building to give protection to all possible types of sounds but it should protect from daily sounds that cannot be avoided. Occassional events are tolerated to a larger extent, but abuse by neighbours (shouting, playing loud music, leaving dogs barking for long etc) are not tolerated, but the building is not blamed for the disturbance. The expectations on the building sound insulation is therefore more modest and we do not need to insulate loud music, parties with large groups of guests etc. This is a matter for the neighbours and the owners to solve. A high satisfaction with the building and its surroundings reduce the risk of annoyance to some extent.

The report lists some sources of noise that could be mitigated and thus less disturbing:

- WC-flushing, sewage, water, structure borne sound
- Doors being closed
- Rapid walks on the floors
- Spin dryers, washing machines in neighbours dwelling etc were tolerated
- Do it yourself noise was annoying

The perceived freedom to speak, play music, have guests etc in ones own apartment seem to correlate well with the perceived noise from the neighbours. However, the vast majority of respondents (95%) say they restrict own noisy behaviors to protect their neighbors and very many of the respondents (80%) consider themselves tolerant of noise from neighbors. This means that the scope for reducing nuisance sounds by behavioral changes and increased tolerances is limited.

The TNO dose-effect investigation showed that the scale and severity of noise annoyance from neighbouring dwellings corresponded well with the national data quoted on the subject and with the results of the RIGO study. 10% had had serious annoyance from these sounds and 32% to some degree (in the RIGO study the figures were 14% and 31% respectively). Almost half of the respondents (47%) said they could hear daily noise from neighbouring dwellings, i.e. considerably more than were disturbed.

Table 1 Priority of hearing (if this occurs at least monthly) and degree of annoyance (if sounds are heard at least monthly) from specific noise sources from neighbouring dwellings.

Table 1 Priority of hearing (if this occurs at least monthly) and degree of annoyance (if sounds are heard at least monthly) from specific noise sources from neighbouring dwellings.

priority of hearing	priority of annoyance	Types of noises or noise source	% heard (at least monthly)	average annoyance with monthly hearing (scale 1-10)	% some annoyance (A28)	% severe annoyance (A72)
1	9	Flushing sounds from toilet	49	3.44	40	10
2	6	DIY sounds	41	4.31	56	17
3	2	Noise from TV/radio/audio turned up loud	37	4.56	57	19
4	3	Slamming of doors	36	4.54	56	19
5	7	Speaking with raised voices or shouting	35	4.24	54	15
6	5	Walking heavily on stairs	34	4.32	53	18
7	8	Dog barking	33	3.62	43	12
8	12/13	'Normal" walking on staircase	32	2.9	33	5
9	15	Noise from walking heavily on floors	31	2.67	27	3
10	4	walking heavily on floors	29	4.48	56	18
11	2/13	Sounds from spindrier or washing machine	28	2.9	31	8
12	11	Noise of showering and/or taking bath	27	2.92	32	5
13	1	Playing special popmusic	25	5.09	65	29
14	14	Speaking normally	23	2.71	30	2
15	10	Noise from TV/radio/audio at normal volume	20	3.22	37	8

The correlation between a normalized airborne sound insulation and subjective annoyance was calculated and displayed in Figure 1:

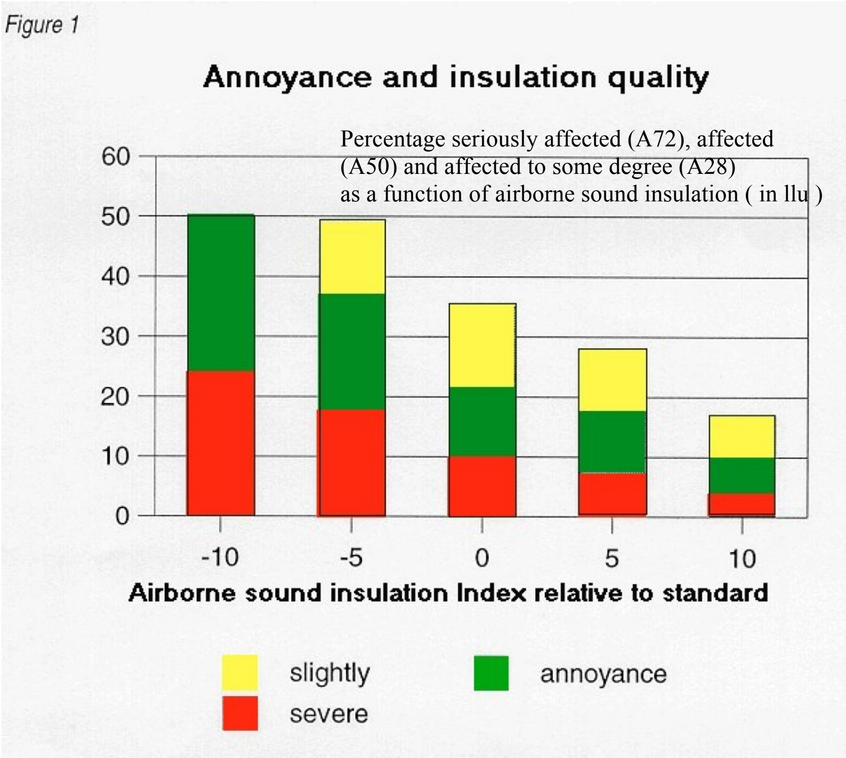
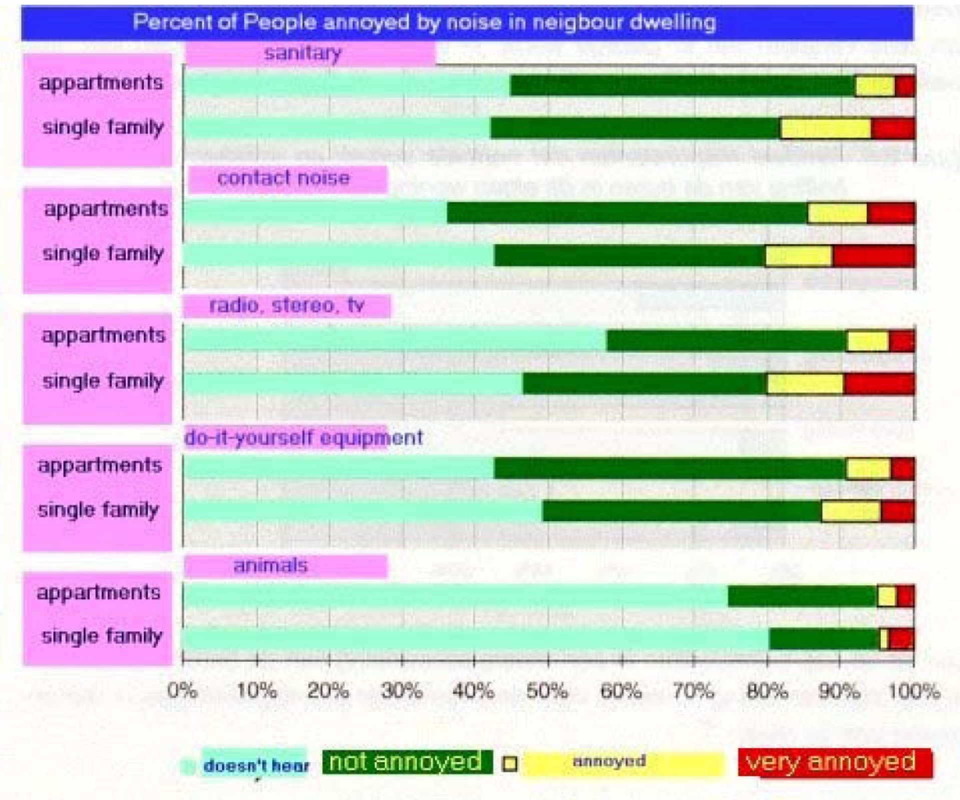


Figure 2 Average annoyance caused by specific noises in neighbouring dwellings as a function of the sound insulation category (GWK)

A summary of the results are displayed in the next figure:



It was also found that the annoyance caused by noise from neighbouring dwellings was closely connected with the rating (in terms of excellent, good, (just) adequate, inadequate or poor) that one gave to the sound insulation of the dwelling in relation to neighbouring dwelling(s).

A further factor was that annoyance was fairly closely connected precisely with "noisy" sounds: mainly special pop music, having the TV/radio/audio equipment on loud, slamming doors and walking heavily on floors. (MOST ANNOYING SOURCES)

The study also showed that the relationship between the "subjective" judgement by residents of the quality of the sound insulation in relation to neighbouring dwelling on the one hand and the dose-units applied on the other is slightly stronger than that between the annoyance and the dose-units referred to above. In other words: the dose-units appear to give a better prediction of the quality rating of the insulation (the "noisiness" of the dwelling) than the annoyance.

The quality judgement of insulation appears to be mainly determined by the sounds of "normal" day-to-day behaviour from neighbours from such "normal" talking, taking showers or baths, the noise from a spin-drier or a washing machine, and "normal" walking on floors and stairs. The poorer the judgement of the insulation, the greater the annoyance experienced from the "normal" behaviour listed above. What is striking is that hearing the sound of a toilet flushing, slamming of doors and barking of dogs from the neighbours appears to have less impact on a good or excellent assessment of sound insulation than other sounds. In other words: it would appear that the sound of the toilet flushing, the slamming of doors, the barking of dogs, etc is not primarily associated with the level of sound insulation; as if one believes that these sounds couldn't be insulated against anyway.

What people consider "normal" depends upon their personal or household situation, but also, for example, the quality of the dwelling, relationship with the neighbours, whether one hears noise from the neighbours oneself and the specific noise that one hears from the neighbours.
There are no indications that norms for ones own noise-producing behaviour differ markedly from the norms applied to the neighbours. If one lives next to neighbours with different norms, the risk of annoyance increases, most (in ascending order) if the norms differ about the time of noise production ending, duration, frequency and loudness. The more the neighbours can be held responsible, the greater the annoyance experienced.

OTHER FACTORS. Finally, there are a number of factors that can be listed which did not display any significant link with annoyance in the present study. These include whether they were dwellings for rental or purchase (according to the inhabitants), the front exterior is thermally and/or acoustically insulated. Nor was any link established with personal characteristics such as sex of respondent, having been born in the Netherlands or not, being hard of hearing or not, level of education and (according to respondents own statements) being part of a busy or calm household.

If one looks in particular at the factors considered which are most closely connected with noise annoyance from neighbouring dwellings, it is found that the greatest reduction in noise annoyance occurs if:

- the judgement of the quality of the sound insulation to the neighbours is improved;
- less annoyance is experienced from "normal" talking at the neighbours;
- Satisfaction with the dwelling (particularly its technical state of repair) is improved.

An increase in annoyance from noise from neighbouring dwellings can be expected if:
- sound insulation in relation to the exterior is improved, but not in relation to adjacent dwellings.

The dose-effect relationship for airborne sounds identified in the study corresponds reasonably well with the results of a previous study (3). Admittedly, the dose-effect regression line is less steep than the line in the previous study (AIRBORNE – ANNOYANCE WORKS). With an Ilu of 0 dB, there are approximately 10% fewer people severely affected and 35% to some extent affected, with an Ilu of +7 dB, approximately 5% severely affected and 25% to some degree affected. In the previous study, there were 10% severely affected and 25% to some degree affected at 0 dB and 2.5% and 10% affected at +7 dB respectively.
…..
To sum up;

The risk of annoyance is largest if what in principle are avoidable "noisy" sounds are heard: special pop music, having the TV/radio/audio equipment on loud, slamming doors, walking heavily on the stairs or on floors, DIY (do it yourself) noises or speaking with raised voices or shouting.

The main conclusion that can be drawn on the basis of the TNO and RIGO studies described above are as follows:

- Annoyance caused by noise from neighbouring dwellings and from the noise of neighbours outdoor activities is a comprehensive and complex problem. This is again confirmed by the present study.
- It was found in establishing the dose-effect relationships that the "heaviness" of the insulation (the dose) has little or no predictive value of the noise annoyance from neighbouring dwellings at individual (personal) level. If individual respondents, however, are grouped by dose (or insulation) categories, it is found that the percentage affected clearly falls in many cases in proportion to the measure of the sound insulation. This particularly applies to those severely affected by the annoyance.
- Major factors that affect noise annoyance from neighbouring dwellings include hearing specific (notably noisy) sounds from the neighbours, satisfaction with ones dwelling in general (notably its technical state of repair) and the individuals opinion of the quality of the insulation of the dwelling (or the 'noisiness'of the dwelling).
- The (physical) units in which insulation quality is expressed is more closely connected with the judgement of insulation quality than with the annoyance experienced. In other words: improving the judgement of the sound insulation is connected with achieving better (measurable) insulation values. Indirectly, although less clearly, this also affects the annoyance.
- Some of the sounds that cause annoyance such as talking at "normal" volume, taking a shower or bath and using the toilet, are a result of activities in which everyone engages and which are unavoidable or virtually so.
- If these sounds can be heard (which is the case in a significant number of dwellings), the "subjective" judgement by residents of the quality of the sound insulation of the dwelling is more negative. This judgement, and thus indirectly the annoyance, can in principle be improved by fitting better insulation. If the respondents are grouped in dose-categories, it is found that annoyance in general and annoyance caused by a number of specific sounds clearly diminishes in proportion to the airborne sound insulation.
- Behaviour which in principle is avoidable such as having a TV/radio/audio on loud, slamming doors, walking heavily on floors and staircases, shouting, drilling and the barking of dogs correlate less strongly with the judgement of the quality of sound insulation in the dwelling. Serious annoyance caused by such factors often can not be avoided by better sound insulation. By far the majority of respondents (95%) claimed that they took account of the neighbours in their own behaviour and a large number of them (80%) considered themselves tolerant of noise from neighbours. This means that the scope for reducing noise annoyance which in principle is avoidable by behavioural changes and raising tolerance levels is limited. In many cases, the annoyance will be caused by noises which could be avoided at certain times, but which are difficult to avoid at all times.
- The study gained some understanding of what the population generally considers still acceptable when it comes to times, duration, frequency and volume of various types of sounds. This enables "general" norms to be set and (policy) decisions to be made on what percentage of (severely) affected is the maximum permissible or feasible. These norms can form the reference framework for residents affected and those causing annoyance, intermediary bodies and enforcers (police e.g.)
- If good sound insulation is in place, people expect to hear less, which means that annoyance may be perceived at lower sound levels. This indicates that it is unlikely that one could ever reduce the noise annoyance from neighbours without behavioural changes. Nevertheless, one can expect that apart from focusing on better 'low-noise design' and care during the construction phase, relatively simple physical measures could be applied more to reduce specific forms of annoyance, notably that caused by "normal" dayto- day sounds. This means that less noise will be produced without having to modify ones behavioural norms.
- If such measures are to be used more, greater publicity will have to be given to it, given their sparing application at present.
- One can expect noise annoyance from "noisy" sounds which cannot always be avoided (such as noisy music from young people in their bedroom, music with windows open during a party with other people, the occasional slamming of doors or walking heavily, elderly people who are hard of hearing having the TV on loud, drilling when doing jobs around the home, etc.) will increase the closer people live together. With "compact building", extra attention will therefore be required to bring about adequate sound insulation against normal sounds, but a greater risk of annoyance connected with a larger number of people in their immediate environment is inherent to compact building.

Norway (Barlindhaug and Ruud)

Barlindhaug and Ruud investigated multi-family residential houses with high-rise and small scale (attached) houses[9]. They concluded about 70 % were satisfied with the sound levels and sound insulation. In attached row-houses, only about 50% were satisfied.

Tabell 5.25 *Fornøyd med lydisolering i forhold til naboleilighet etter hustype. Bare de som oppgir å bo i hus med flere boliger. Prosent*

	Ene- og vertikal-delte boliger	Horison-taldelte boliger	Blokk med 3+ etasjer	Alle
Misfornøyd	16	27	14	17
Verken fornøyd eller misfornøyd	13	18	12	13
Fornøyd	71	54	74	69
Sum	100	100	100	100
N=	258	205	607	1070

Germany, (Kurz and Fischer)

Kurz and Fischer[10] examined sound insulation measurements made within legal court claims, where the habitant complained about the fulfillment of the legislation. Their conclus-ion is supported by the following graph, where 15% of the habitants complaining would cor-respond to R'w 54 dB for partition walls. Another investigation by Kötz returned a higher value for the same fraction, R'w 56 dB.

Eine Grenze von ca. 15 % Klagefällen liegt bei unserer Auswertung im Bereich eines bewerteten Schalldämm-Maßes von $R'_w \approx 54$ dB.

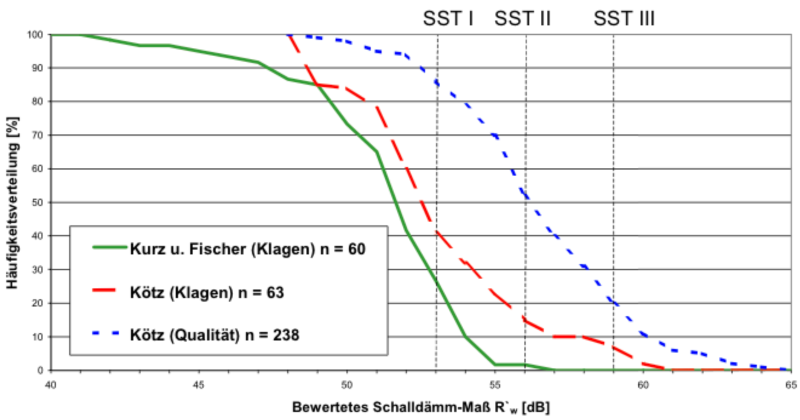


Abbildung 1: Häufigkeitsverteilung der Luftschalldämmung von Wohnungstrennwänden

For the vertical direction, i.e. through the floors, a 3 dB higher sound reduction index is needed to obtain less than 15% dissatisfied habitants.

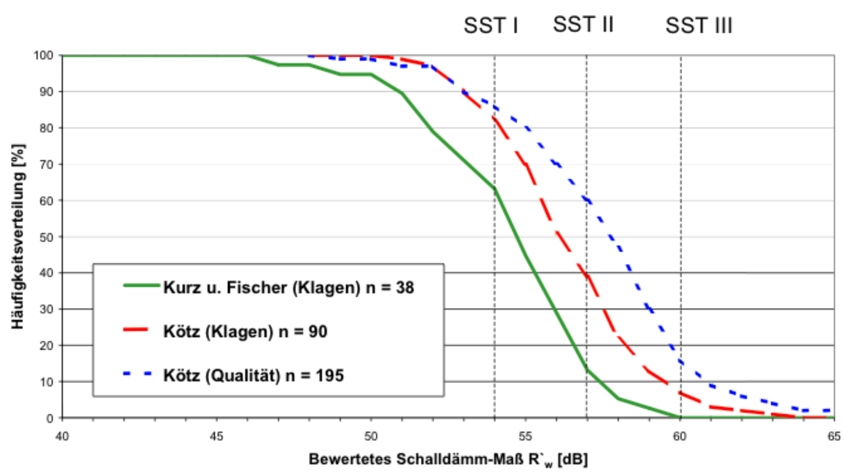


Abbildung 2: Häufigkeitsverteilung der Luftschalldämmung von Wohnungstrenndecken

This difference is believed to be related to two factors. One is that in the vertical direction, the proportion of the room volume to the partition area is less than between rooms in the horizontal direction. The other explanation is that the partition walls typically face only 1-2 rooms whereas sound through the floors are heard in all rooms.

For partition walls between attached houses, the insulation needs to be better, about R'w 62 dB (<15% dissatisfied):

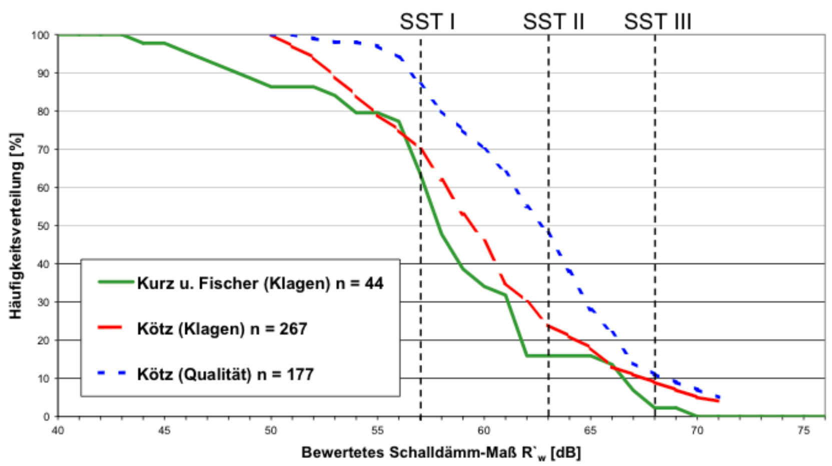


Abbildung 5: Häufigkeitsverteilung der Luftschalldämmung von Haustrennwänden

For impact sound, the following results. To obtain less than 15% dissatisfied with impact sounds from heavy floors with floating floors and hard floor coverings, the L'n,w must be less than 45 dB:

15 % Klagefällen liegt im Bereich eines bewerteten Norm-Trittschallpegels von $L'_{n,w} \approx 45$ dB.

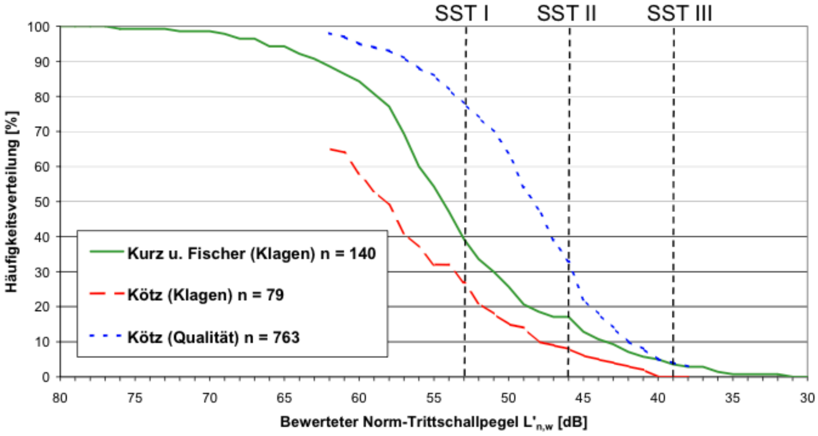


Abbildung 3: Häufigkeitsverteilung der Trittschalldämmung von Wohnungstrenndecken

For noise from building service equipment, the habitants complain about the use of the equipment (e.g. WC) rather than the normal operation. The main finding is that L_{pAFmax} 32 dB corresponds to 15% dissatisfied habitants.

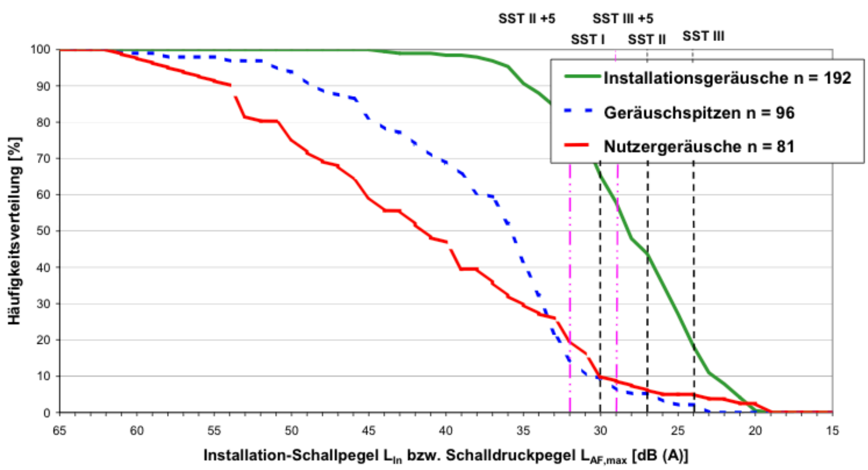


Abbildung 6: Häufigkeitsverteilung der Geräusche von Wasserinstallationen

Mortenssen, DTU Denmark: Listening tests

Mortenssen made structured listening tests in the laboratory, with artificially shaped sound spectra. Some of the main findings about the relation between exposure and response (annoyance):

For the impact noise examples a slope of 4.1-4.3% more annoyed per dB(A) increase in level is found for the complete range of responses, whereas if only the response range from 20% to 80% annoyed is considered, the slope is 6.3 % for the presentations of children playing. The slope for music noise is more flat due to the much saturated response range and only produces a 2% /dB(A) slope for the full range, but a more steep slope of 4.3% for the response range from 20% to 80% annoyed.

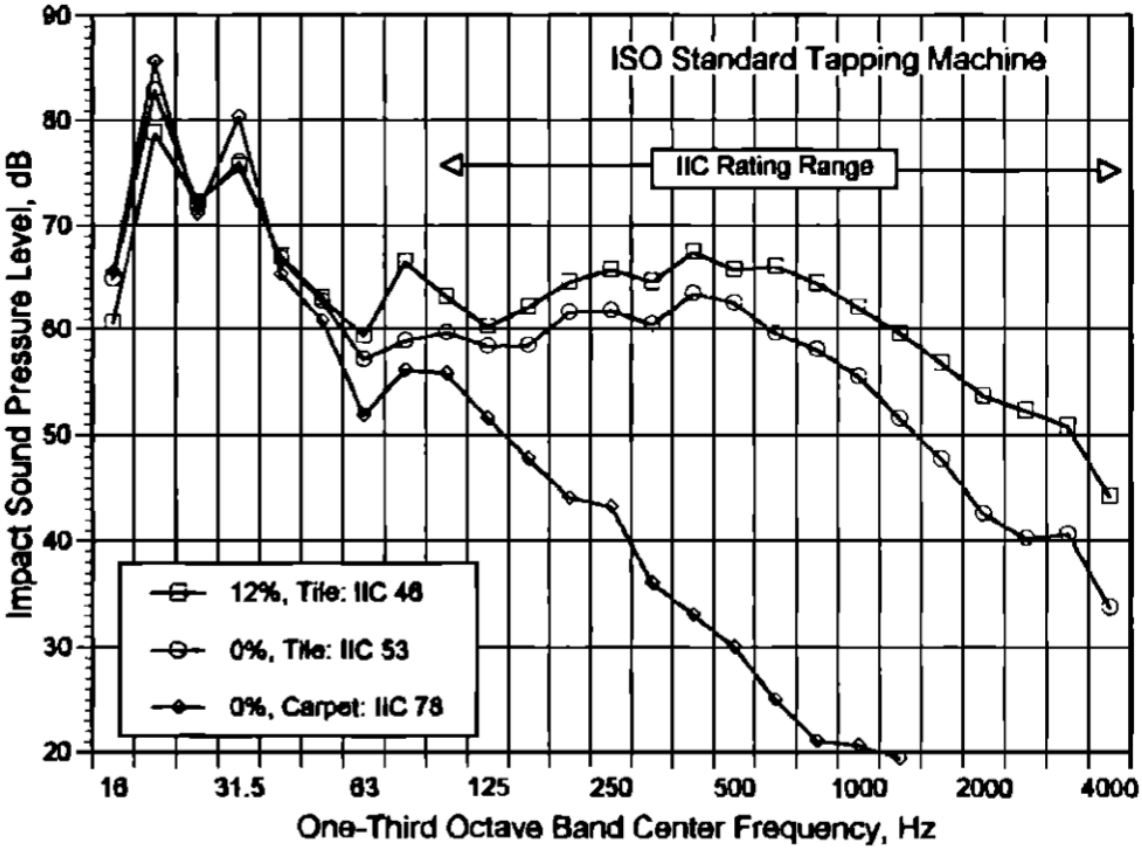
In summary, the experiments have shown that noise from neighbours transmitted through light constructions is rated more annoying than noise transmitted through heavy constructions with the same sound reduction index or impact noise level. The difference is the higher low frequency content in noise transmitted through light constructions.

Blazier & DuPree, USA

The problems with high impact sound levels at very low frequency was high-lighted in the U.S by Warren Blazier and Russell DuPree in 1994.[11] This problem is addressed in the AkuLite project in Sweden, conducted in 2010-2012.

An investigation of low-frequency footfall noise in multifamily, wood-frame residential construction has led to the conclusion that, at present, there is no economically practical method of avoiding the perception of "thuds" and "thumps" in rooms beneath the walking surface. The IIC rating of a floor system is *meaningless* with respect to the perception of these low-frequency components of footfall noise, because the methodology ignores the frequency spectrum below 100 Hz; the peak energy in a footfall spectrum occurs at the fundamental natural frequency of the floor/ceiling system, which with typical light-weight structural framing is usually between 15 and 30 Hz. Although the construction of floated floors, or the addition of carpeting, is effective in attenuating mid- to high-frequency components of footfall noise, the data indicate that the amplitude of floor response at the natural frequency is actually *increased*. It is believed that this occurs because walking on a more resilient system results in a longer rise-time of the footfall waveform, which permits more low-frequency energy to be coupled into the system. The principal factor controlling the perception of low-frequency footfall noise is the point-stiffness of the structural floor system. In normal light-weight residential construction, the stiffness is usually much less than that required to avoid an audible disturbance. However, such problems are relatively rare in *concrete* structural floor systems, due to their substantially increased stiffness.

One diagram from their paper illustrates the low-frequencies below 50 Hz:



Bradley, NRC Canada

In a short paper from 2001[12], Bradley reports a field survey made in Canada:

" The survey included extensive face-to-face interviews in subjects' homes as well as complete sound transmission loss measurements of party walls between homes and ambient noise measurements in each home over a complete 24 hour period. A total of 600 subjects were interviewed in 300 pairs of homes. Homes were equally distributed among the combinations of owners and renters, row housing and apartments and 3 cities (Toronto, Vancouver and Montreal)."

Bradley observed a high correlation between sound insulation and several subjective opinions related to noise from neighbours:

" ..when subjects were asked if they would like to move from their present home, the percentage saying yes significantly decreased with increasing measured STC of their party wall. (See Figure 1). Of the people saying they would like to move in each of the 8 STC groups, 94 to 100 % of them gave a noise related reason. Sound insulation is clearly a major cause of people wanting to move and noise problems appear to be an almost ubiquitous reason for wanting to move.

When subjects were asked how satisfied they were with the building in which they lived, the responses were significantly related to measured STC values (see Table I) and subjects with better sound insulation were more satisfied with their building.

Subjects' responses concerning how considerate their neighbours were, were also significantly related to measured STC values. That is, subjects with lower sound insulation tended to blame their neighbours as being less considerate. Poor sound insulation between homes is thus seen to be a potential cause of social disruption.

When asked how often they were awakened by noises from neighbours in their building, their responses were again significantly related to measured STC values (See Table I). Thus the quality of resident's sleep is related to the amount of sound insulation between their homes.

When subjects were asked to rate the sound insulation between them and their neighbours, their responses were significantly related to measured STC values as shown in Figure 2. Subjects are aware of the quality of the sound insulation; it is important to them, and it affects their quality of life."

The last observation supports the findings at TNO, habitants are capable of judging the sound insulation of their homes, the correlation to measured STC is very high.

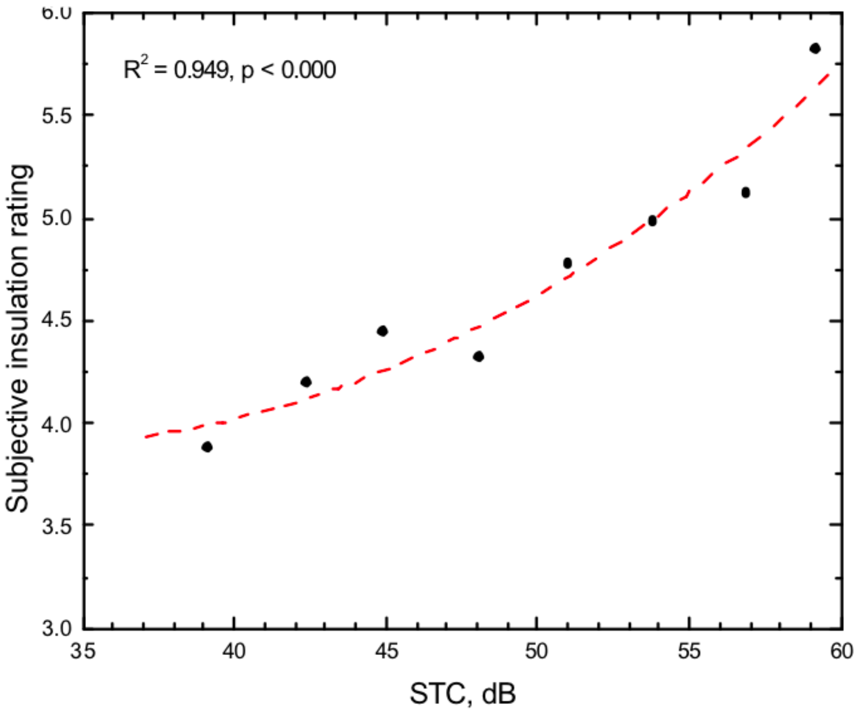


Figure 2. Subjective rating of sound insulation vs. STC.

STC is evaluated from third octave bands in a similar manner as for R'w and it is highly correlated to R'w. The main difference is that the STC uses an 8-dB limiting rule.

Bradley concludes:
" For most types of sound, the benefits of sound insulation only occur for STC ratings substantially above STC 50. For music related sounds, the sound insulation becomes more effective for STC values well over STC 55. Responses are close to 1 for an STC of 60 indicating that at this point residents would not hear these sounds from their neighbours 'at all' and they were 'not at all annoyed' by them. An effective STC of 55 is therefore recommended as a realistic goal and STC 60 as a more ideal goal for party wall sound insulation."

It is not possible to convert these suggestions to $R'_w + C_{50\text{-}3150}$ goals without having access to the STC-frequency curves, but a rough estimate would be that STC 60 corresponds to $R'_w + C_{50\text{-}3150}$ 55-57 dB on the average, possibly less for light weight partitions.

In a a recent paper, Park and Bradley used listening tests[13] to compare different weighting systems in a systematic way. They conclude in their abstract:
" This paper reports the results of an evaluation of the merits of standard airborne sound insulation measures with respect to subjective ratings of the annoyance and loudness of transmitted sounds. Subjects listened to speech and music sounds modified to represent transmission through 20 different walls with sound transmission class (STC) ratings from 34 to 58. A number of variations in the standard measures were also considered. These included variations in the 8-dB rule for the maximum allowed deficiency in the STC measure as well as variations in the standard 32-dB total allowed deficiency. Several spectrum adaptation terms were considered in combination with weighted sound reduction index (R_w) values as well as modifications to the range of included frequencies in the standard rating contour. A STC measure without an 8-dB rule and an R_w rating with a new spectrum adaptation term were better predictors of annoyance and loudness ratings of speech sounds. R_w ratings with one of two modified C_{tr} spectrum adaptation terms were better predictors of annoyance and loudness ratings of transmitted music sounds. Although some measures were much better predictors of responses to one type of sound than were the standard STC

and R_w values, no measure was remarkably improved for predicting annoyance and loudness ratings of both music and speech sounds."

Two Figures from the paper illustrate the correlation results, and the need to consider the type of sound by the use of a least 2 spectra:

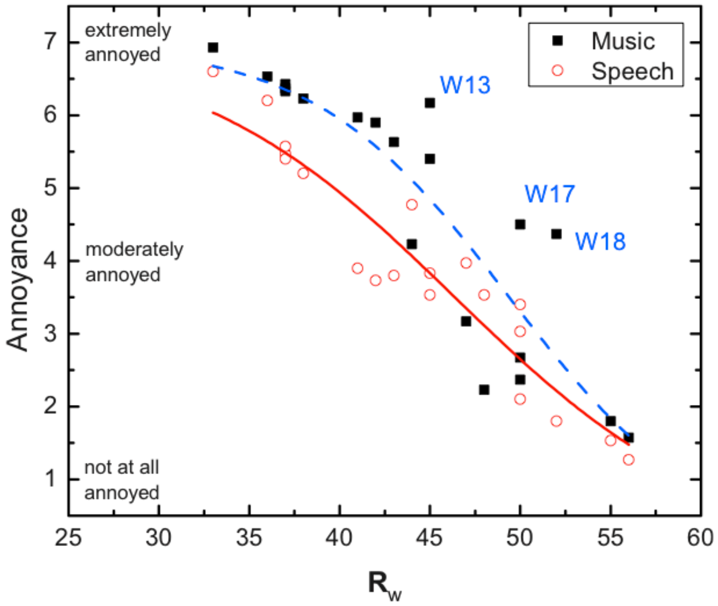


FIG. 3. (Color online) Mean annoyance ratings versus R_w values for music and speech sounds [music: R^2=0.798 (0.728); speech: R^2=0.890 (0.856)]. (Values in parentheses are R^2 for annoyance versus STC values from Fig. 2.)

TABLE II. R^2 values for Boltzmann equation fits to mean loudness and annoyance ratings plotted versus sound insulation measures based on R_w with various spectrum adaptation terms. R^2 values equal to or greater than 0.95 are in bold font.

Measure	Annoyance speech	Annoyance music	Loudness speech	Loudness music
R_w	0.890	0.798	0.933	0.779
R_w+C	0.741	0.918	0.821	0.900
$R_w+C_{tr(100-3150)}$	0.566	**0.950**	0.676	**0.960**
$R_w+C_{tr(50-5000)}$	0.388	0.943	0.482	**0.980**
$R_w+C_{tr\_mod}$	0.541	**0.983**	0.634	0.991
R_w+C_{mod}	**0.975**	0.580	0.973	0.556
$R_{w(63-5000)}$	0.769	0.940	0.848	0.907
$R_{w(160-5000)}$	**0.972**	0.562	...	...

BRI, Poland – survey and measurements in Poland

Izewska[14] has compared measurements to various types of subjective assessments in 200 polish buildings erected with 4 types of prefabricated concrete element systems. The results indicate a increase of annoyance when the sound insulation does not fulfill their regulations, as seen in the following figures from the paper:

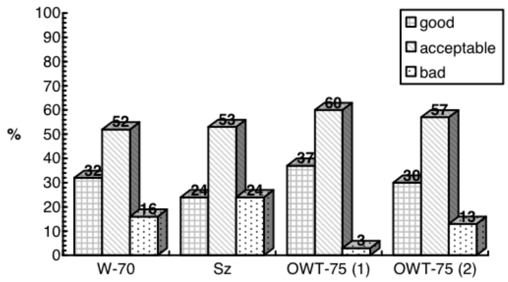


Fig.1. General rating of acoustic climate in dwellings in the various building systems (survey results)

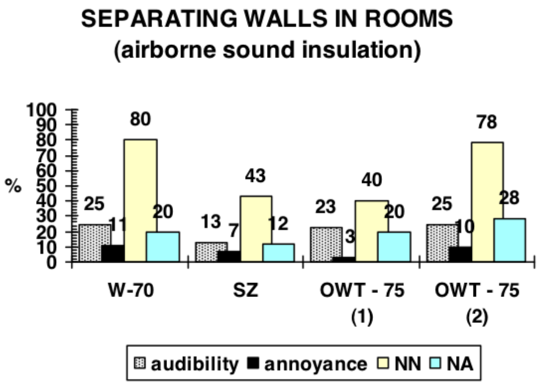


Figure 3. Rating of sound insulation of separating walls between the apartments in rooms where NN - measurement results not meeting the standard requirements i.e. $R'_w < 51$ dB, NA - worse than required by at least 3 dB i.e. $R'_w \leq 48$ dB.

Figure 3 compares the two assessment: subjective - presenting percentage of audibility and annoyance of noise emitted through the walls and objective - providing the percentage of measurement results NN not meeting the standard requirements (where $R'_w < 51$ dB) and percentage of results NA worse than required by at least 3 dB (where $R'_w \leq 48$ dB).

Such negative assessment of the vertically insulation between rooms is not only caused by acoustic properties of floors but also of pipes and ducts. Generally, worse subjective evaluation of floors is justified by worse, than in case of the walls, objective evaluation based on the results of acoustic measurements conducted in the surveyed apartments. This is marked on the figures giving a subjective evaluation of audibility and annoyance and the measurement results presented as a percentage of dwellings in which the requirements are not met by standards (NN) and the percentage of dwellings in which the lack of sound insulation in relation to the requirements is greater than 3 dB (NA).

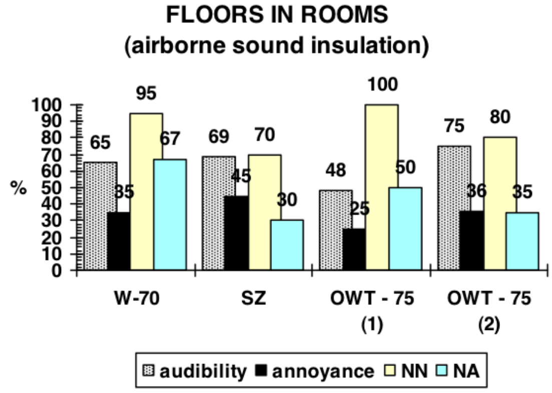


Figure 4. Rating of airborne sound insulation of floors in rooms
(NN - measurement results R'_w < 51 dB, NA - $R'_w \leq 48$ dB)

As was found also by Lang, the vertical direction is much worse than the horizontal, i.e. the insulation of the floors need to be better than the walls. The criteria need to be stricter.

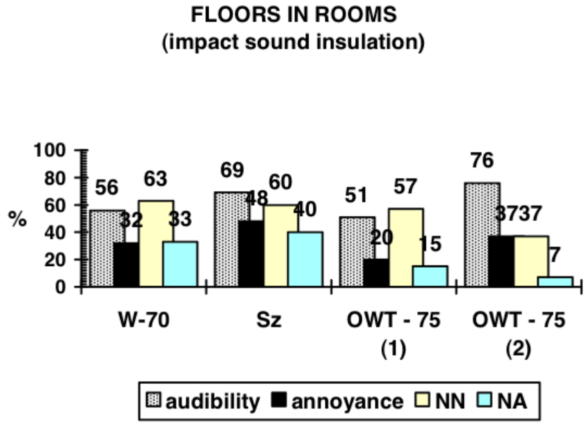


Figure 6. Rating of impact sound insulation of floors in rooms
(NN - measurement results $L'_{n,w}$ > 58 dB, NA -. $L'_{n,w} \geq 61$ dB)

The annoyance from impact sound is obvious and stricter criteria should be used.

Table 1. Assessment of noise from the equipment installation in kitchens, bathrooms and toilet, passing through floors and separating walls

Construction system	Type of room	Subjective assessment of installation noise			Measurement results	
		Number of samples	Audibility, %	Annoyance, %	L_{Amax}, dB	$s(L_{Amax})$, dB
W - 70	kitchen	133	41	18	40.7	1.4
	bathroom	133	62	25	43.4	1.4
	w.c.	102	68	29	48.7	1.7
Sz	kitchen	127	44	28	40.3	1.4
	bathroom	127	45	17	44.7	1.2
	w.c.	83	67	40	47.7	1.7
OWT – 75 (1)	kitchen	116	62	16	42.4	1.0
	bathroom	116	63	16	42.6	1.2
	w.c.	116	76	21	48.7	1.1
OWT - 75 (2)	kitchen	83	33	13	40.7	1.0
	bathroom	83	40	15	41.4	0.9
	w.c.	83	71	30	46.7	1.0
H	kitchen	75	52	20	41.8	1.3
	bathroom	75	61	20	46.8	1.3
	w.c.	75	64	33	48.6	1.8
Average	kitchen	534	45.6	19.0	41.2	1.2
	bathroom	534	54.2	18.6	43.8	1.2
	w.c.	459	69.2	28.6	48.1	1.5

Izewska summarizes the findings on installation noise:
”It results that the installation noise is audible when average maximum value of LAmax is higher than 35.5 ± 2.0 dB. Noise is considered as annoyed when their value of LAmax is higher than 41.6 ± 2.0 dB.” These values are higher than Sweden has used so far.

Germany, DEGA Emphelung 103 (sound classification scheme A-F)

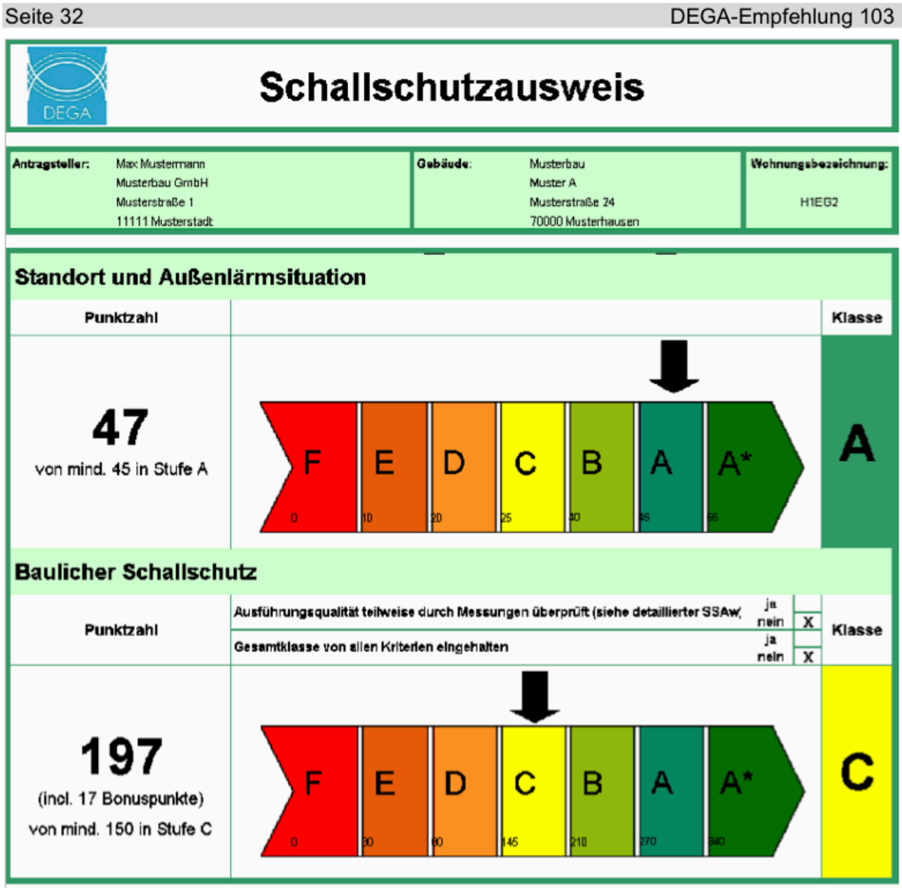
The German acoustical society has issued a sound classification scheme[15] to support a unified rating A*-F of various types of residential houses, where C is intended as minimal performance for new houses, B-A-A* for better performance and D-F for existing stock. The subjective meaning of the performance classes A*-F is described in terms of audibility and disturbance. Class C is clearly marked as a minimum requirement, where occassional disturbance may be expected. Class B and higher are adviced in cases better performance is asked for.

The scheme incorporates the common types of requirements but also noise from habitants, e.g. mailbox closed, closing cupboards and interior doors, WC lid, children playing in a bath tube etcetera. This is to advice on solutions to remove such noise in adjacent dwellings. The structure borne sound from habitants standing and urinating in their WC is particularly disturbing. The measurement is made with a small tapping machine (*Kleinhammerwerk*), however this machine is not defined in the paper. The idea is to make this noise comparable to impact noise and to have a robust measurement procedure, less prone to random errors from background noise sources.

The criteria of class D/C/B are (condensed):

- R’w 53/57/62 dB for walls, R’w 54/57/62 dB for floors
- R’w 27/32/37 dB for doors to closed spaces, R’w 37/42/45 to habitable rooms
- L’n,w 53/46/40 dB for floors, L’n,w 53/46/40 dB for stairs etc
- $L_{pAFmax,n}$ 30/25/20 for water installations and use of WC, L_C-L_A ≤ 20 dB (advice)
- $L_{pAFmax,n}$ ≤ 40/35/30 for other ’user noises’ (advice)

After measurements, a classification label is issued, that reminds of the energy declaration of machinery:



Germany, VDI 4100

The German standard applies three classes of sound/sound insulation:
SSt I addresses minimum requirements, SSt II better conditions and SSt III high comfort.

Tabelle 1: Wahrnehmung von Geräuschen aus Nachbarwohnungen und Zuordnung zu drei Schallschutzstufen (SSt).
(VDI 4100 Tabelle 1 und E-DIN 4109-10 Tabelle A 1)

Art der Geräuschemission	Wahrnehmung der Geräusche aus der Nachbarwohnung, abendlicher Grundgeräuschpegel von 20 dB(A) vorausgesetzt		
	SSt I	SSt II	SSt III
Laute Sprache	verstehbar	im allgemeinen verstehbar	im allgemeinen nicht verstehbar
Sprache mit angehobener Sprechweise	im allgemeinen verstehbar	im allgemeinen nicht verstehbar	nicht verstehbar
Sprache mit normaler Sprechweise	im allgemeinen nicht verstehbar	nicht verstehbar	nicht hörbar
Gehgeräusche	im allgemeinen störend	im allgemeinen nicht mehr störend	nicht störend
Geräusche aus haus-technischen Anlagen	unzumutbare Belästigungen werden im allgemeinen vermieden	gelegentlich störend	nicht oder nur selten störend
Hausmusik, laut eingestellte Rundfunk- und Fernsehgeräte, Parties	deutlich hörbar		im allgemeinen hörbar

Tabelle 2: Bauakustische Kennwerte für den Schallschutz in Mehrfamilienhäusern
Schallschutzstufen (SSt) nach VDI 4100 und E-DIN 4109 Teil 10

		akustische Größe	SSt I DIN 4109	SSt II	SSt III
Luftschallschutz zwischen fremden Aufenthalts-räumen	horizontal	R'_w in dB	53	56	59
	vertikal	R'_w in dB	54	57	60
Luftschallschutz zwischen Aufenthaltsräumen und fremden Treppenhäusern und Fluren		R'_w in dB	52	56	59
Trittschallschutz zwischen Aufenthaltsräumen und fremden Räumen		$L'_{n,w}$ in dB	53	46	39
Trittschallschutz zwischen Aufenthaltsräumen und fremden Treppenhäusern		$L'_{n,w}$ in dB	58	53	46
Geräusche von Wasserinstallationen		L_{In} in dB(A)	30	30 *	25 **
Geräusche von sonstigen haustechnischen Anlagen		L_{AFmax} in dB(A)	30	30 *	25 **
Geräusche von Gewerbebetrieben		L_r in dB(A) nach TA Lärm	35	35	-
Luftschallschutz gegen Außenlärm		R'_w in dB	DIN 4109	DIN 4109	DIN 4109 + 5 dB

*) nach E-DIN 4109-10 L_{In} = 27 dB(A)
**) nach E-DIN 4109-10 L_{In} = 24 dB(A)

Germany, Neubauer

Neubauer[16] investigated the relation between airborne sound insulation of floors in 6 field cases (where complaints have been reported) and the audibility of each case. The $R'_w + C_{100\text{-}3150}$ range from 50 to 60 dB in these cases.

” it is investigated various situations, where a separating floor was complained of not having sufficient airborne sound insulation. Measurement tests of airborne sound insulation of the separating floor were carried out according to EN ISO 140-4. In all (6) cases the construction consists of a concrete floor base of thickness 180 mm with a floating floor and .. flanking plastered masonry walls.”

Neubauer compares the sound levels below the floors with the background noise levels, and conclu-des: ” In order to categorize an appropriate sound insula- tion it is needed to specify a sound source level and a background noise level. For this study a sound source level of 78 dB(A) and a background noise level of 25 dB(A) was used to classify an average value for living environment and neighbourhood noise. The comparison of the calculated loudness level and the threshold of hearing with respect to the background noise level yield the subjective assessment of the per- ceived sound level. … As a result of the study it was proposed to support the $D_{nT,w} + C$ rating due to the fact, that it markedly improves the strength of the relationship between subjective acceptability and the insulation rating.”

Table II - Subjective perception of airborne sound and its subjective assessment depending on source sound level.

Spectral corrected standardised sound level difference $D_{nT,w}+C$		Perception of airborne sound and its subjective assessment
Raised voice 78 dB(A)	Loudness level difference ΔL_N	
Background noise 25 dB(A)		
63 dB	2 phon	hardly audibly
61 dB	5 phon	audibly, however not to understand
58 dB	8 phon	audibly and partially to understand
54 dB	11 phon	well audibly
≤ 50 dB	≥ 12 phon	well audibly and to understand

In Table II the proposed spectral corrected standardised sound level differences and their subjective assessments are presented. The evaluation of the quality of the airborne sound insulation is depending on background noise and source sound level.

Neubauer finally recommends a minimal value of the airborne sound insulation of floors:
" …. It is proposed from a subjective point of view a *DnT,w + C* ≥ *58* dB for reasonable acoustical comfort in dwellings"

Scotland, Robin MacKenzie Partnership

Smith et al[17] are currently investigating relationships between sound insulation and the opinions of the habitants. An excerpt of results give an impression of these relationships. Cupboards and audio systems cause the most disturbance:

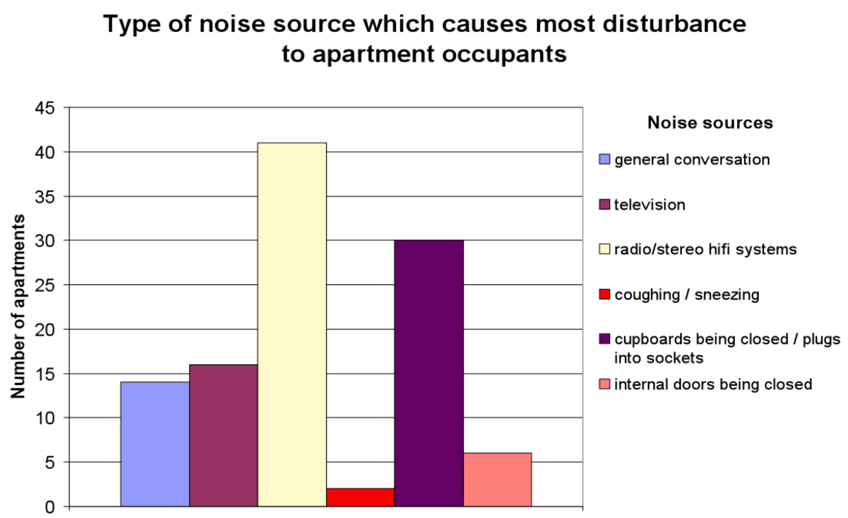


Figure 4.4

In the vertical direction, the impact sound insulation (footfall noise) of the floor seem to be the most important:

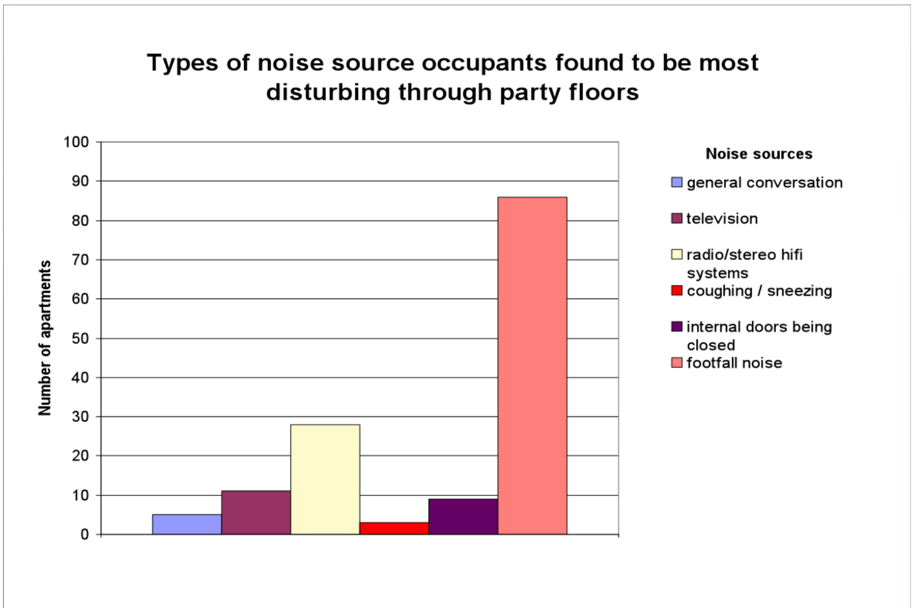


Figure 4.9

For both party walls and floors, it seems that the required sound insulation 53 dB is sufficient for satisfactory performance, but good performance would require 3 dB higher insulation (56 dB).

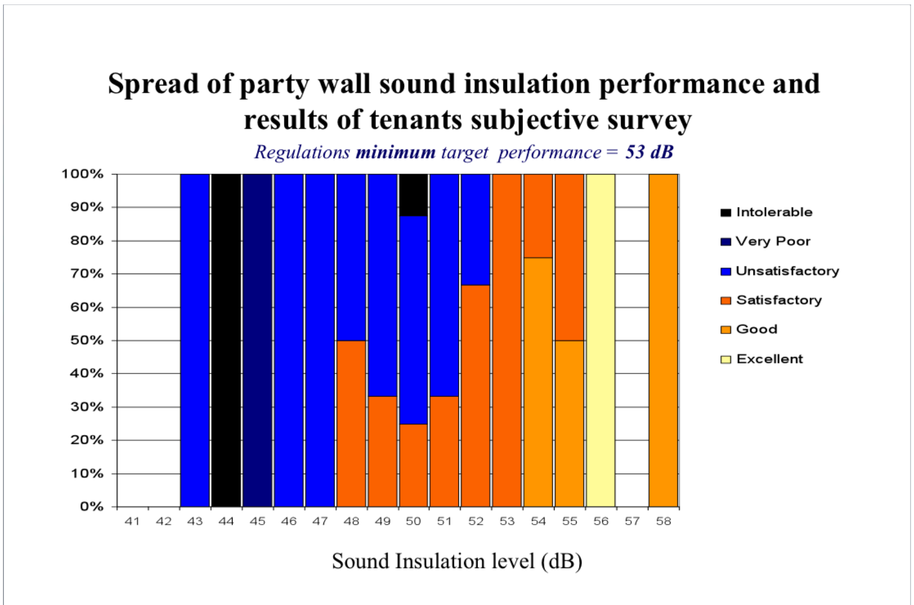


Figure 4.7

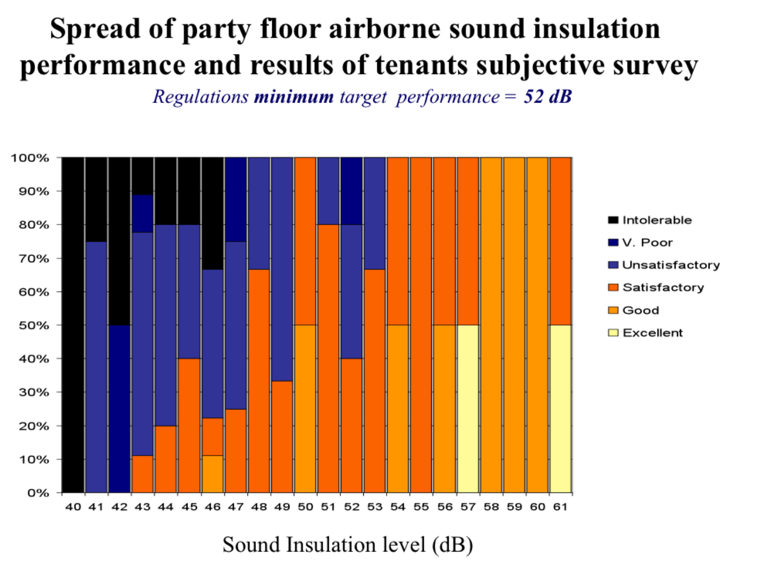


Figure 4.12

Sweden, Hagberg

The relationships between subjective rating of footfall noise on a 7-graded scale was correlated by Hagberg (2005[18]) with the measured impact sound pressure level according to international standards, in a variety of buildings built in the last 40 years.

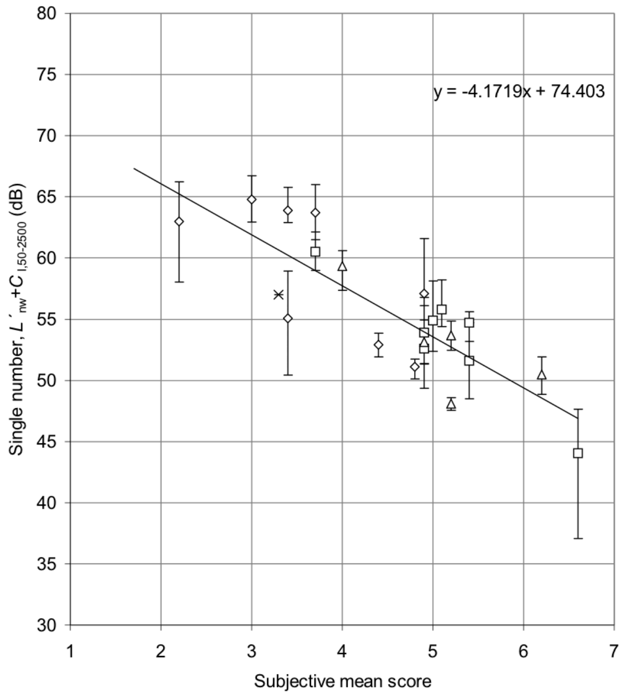
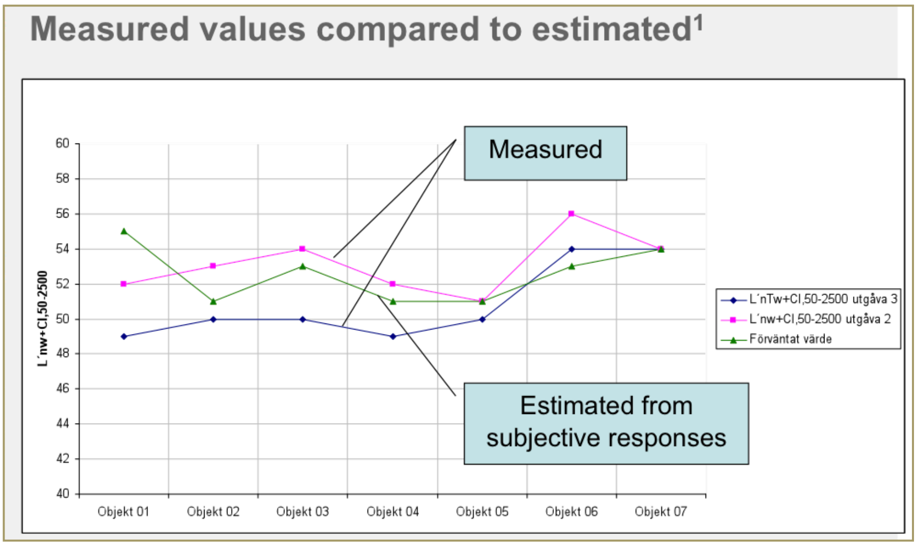


Figure 8. Linear regression for the whole data sample, $L'_{n,w} + C_{I,50\text{–}2500}$ vs subjective grading; = concrete structures, Δ = hollow concrete structures, ◇ = wooden floor structures, × = lightweight steel structures.

Hagberg and Simmons[19] presented results of a study in 7 new buildings, where a reversed method was applied. The opinions of the habitants, taken as the average of the survey of each building, was used to estimate the normalized impact sound pressure level in each building. These estimates were then compared to the actually measured values. The agreement with the upper curve is good. Note: The bottom curve is misleading in this context, it refers to $L'_{nT,w} + C_{I,50\text{-}2500}$ which was not evaluated from the surveys.



The airborne sound insulation has not yet been correlated to the enquiry results, but this is planned for in 2011 within the AkuLite project.

Simmons akustik & utveckling ab
Christian Simmons

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