ACOUSTIC QUALITY OF DWELLINGS, A CONCEPT OF UNIFORM CLASSIFICATION SCHEME

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Summary

Building acoustics is not very well represented in building performance rating systems. The probable reason is the lack of coherent acoustic indicator for the whole building. Airborne and impact sound insulation are considered separately, as well as the level of noise penetrating from outside and from technical equipment. Different countries use different single number quantities for the evaluation. Hence, it is difficult to catch acoustic quality in a simple way with so many diverse indicators. Regulations existing in different European countries are a compromise between expectations, comfort, local conditions and possibilities. The paper presents a study on the possible acoustic categorisation within open building system, the assessment tool similar to the number of stars for a hotel quality or e.g. the energetic class of a fridge. It takes into consideration requirements in different European countries and general relationship between values of different acoustic indicators in use. Acoustic class should clearly define the quality of a building, influence the price but guarantee chosen level of a comfort allowing for tailor-made buildings for different users. Adopting uniform classification scheme as an assessment tool in open building system can be a step towards harmonization of acoustic criteria and requirements around Europe.

Keywords: building acoustics, sound insulation, noise, rating, indicators

1 Introduction

The adverse effects of noise on humans and their health are well known and confirmed by the results of numerous researches. In a residential building even low level of noise may be annoying, disturbing and irritating. Noise disrupts relaxation, impairs task performance, make difficult focusing attention. Excessive noise may disturb sleep or cause falling asleep difficult. Neighbouring noise destroys intimacy and privacy inside dwellings. In such a way noise affects society altering the day to day behaviour, increases aggression, unfriendly behaviour towards others, causes resignation, changes in mood, lack of activity, etc. The list of detrimental effects of noise cited by WHO (2000) is very long. Such effects are not easy to measure but are certainly of vital importance when talking about development of healthy and active society. Navrud (2002) emphasise also the economic aspect of noise.

In general opinion the acoustic quality of a building plays prominent role for inhabitants, but as far it seems difficult to fit it into sustainable development frame. Building acoustic and the protection against noise is not very well represented in building performance rating systems, the probable reason is the lack of coherent acoustic indicator for the whole building.

The vision of open system for manufactured building ManuBuild http://www.manubuild.org/ is focused on the needs of all stakeholders, particularly on the end user requirements. Clear and uniform assessment criteria and coherent indicators, which can be easily understood by a client regardless of the building location, play pivotal role in proper and precise defining these requirements. From a perspective of an open building system functioning on the open market the actual legal situation in building acoustics is really complicated. Several different indicators are in use in different countries and the level of minimum standard of performance differs within a wide range. The aim of this study is to investigate the possibility of developing uniform acoustic classification scheme for multifamily buildings which takes into account different requirements existing in different European countries.

2 Legal requirements in residential buildings

2.1 Sound Insulation

Internal partitions should protect inhabitants against noise generated in the adjacent room by human activity, household devices, TV and audio sets, plying children etc. Walls and floors should provide adequate intimacy and privacy. Internal partitions are evaluated in terms of airborne sound insulation (walls and floors) and impact sound insulation (floors only). Single number quantities for airborne sound insulation are defined by EN-ISO 717. Three basic indicators (R'_w, $D_{nT,w}$, $D_{n,w}$) and two spectrum adaptation terms (C and C_{tr}) are given by the standard. Each spectrum adaptation term may be determined within different range of frequency. Hence, theoretically all combinations of basic indicators and spectrum adaptation terms give 27 single number quantities which can be used for the assessment. In practice eight different indicators are used in different countries to express minimum requirements for separating partitions (table 1). Two countries only, Sweden and UK, apply indicators more sensitive to low frequency behaviour but each of them represents different approach by using $C_{50\text{-}3150}$, and C_{tr} respectively.

Tab. 1 Airborne sound insulation, indicators used in different countries

Indicator	**Countries**
R'_w	Czech Republic, Denmark, Estonia, Finland, Germany, Hungary, Iceland, Italy, Lithuania, Latvia, Norway, Slovenia, Slovakia,
$R'_w + C$	Poland
$R'_w + C_{50\text{-}3150}$	Sweden
$D_{nT,w}$	Austria, Belgium,
$D_{nT,w} + C$	France, Holland, Switzerland
$D_{nT,w} + C_{100\text{-}5000}$	Spain
$D_{nT,w} + C_{tr}$	UK
$D_{n,w}$	Portugal

EN-ISO 717 defines also two basic indicators and two spectrum adaptation terms for impact sound insulation. The number of possible combinations is not as big as in the case of airborne noise, in practice four single number quantities are in use in different European countries (table 2).

Tab. 2 Impact sound insulation, indicators used in different countries

Indicator	**Countries**
$L'_{n,w}$	Czech Republic, Denmark, Estonia, Finland, Germany, Hungary, Iceland, Italy, Lithuania, Latvia, Norway, Poland, Portugal, Slovakia, Slovenia,
$L'_{n,w} + C_{I,50\text{-}2500}$	Sweden
$L'_{nT,w}$	Austria, Belgium, France, Spain, UK
$L'_{nT,w} + C_I$	Holland, Switzerland

Beside legal requirements for minimum standard several countries have adopted local classification schemes defining higher acoustic quality of a building which is not mandatory but, if achieved, it assures higher level of comfort and quality. Such local schemes are in use in Nordic countries, France, Holland and Germany.

2.2 Noise Level

Noise from technical equipment and from outside sources is usually considered separately. In general, service and installation noise is perceived as more irritating and annoying than transportation noise penetrating from outside. Service noise may be continuous (ventilation, air-conditioning, heating etc.) or in a form of short time repetitious acoustic events (plumbing, elevators, rubbish chutes, garage doors, etc.). Specific noise produced by sanitary appliances (wash basin, bathtub, shower, water-closet etc.), may be really annoying especially when our neighbour’s daily lifestyle and schedule differs from our own habits. Individual reaction to such diverse noise sources may be different and it depends not only on the sound pressure level.

Perception of transportation noise of the same level also depends on the type of source. Aircraft noise is considered more annoying than road traffic noise, while railway noise is more tolerable than traffic noise. Dose response curves, proposed by Position Paper (2002) for the assessment of social exposure to environmental noise, take into consideration different perception of various transportation noise.

To allow for different characteristics and effects of noise EN ISO 16032:2002 and EN ISO 10052:2003 standards define 18 single number quantities which can be determined and used for the assessment of noise level inside a building. In general maximum and equivalent sound level is considered, when A-weighted and C-weighted values can be used with “S” or “F” time weighting. The values can be standardized to reverberation time of 0,5s or normalized to sound absorption area of 10 m^2. It gives 18 basic combinations. Besides, the noise level is usually assessed separately within day time, during the night or for the whole 24 hours. In the case of outside noise the criterion of minimum sound insulation for external wall depending on noise level outside is also in use instead or parallel to inner noise level limits. Furthermore, Directive 2002/49/EC of the European Parliament and of the Council has introduced long term indicators L_{DEN} and L_N for the assessment of environmental noise management and strategic noise mapping so eventually limit values for noise penetrating from outside should be coordinated with these indicators.

2.3 Reverberant conditions

Room acoustics and proper reverberation time, beside concert halls and different performance rooms, plays important role for spaces in public buildings, particularly where the intelligibility is crucial for the main function of a room e.g. classrooms, open plan offices, conference rooms, auditoria etc. or spaces which need proper acoustical climate or intimacy such as restaurants, cafeterias retreating rooms. In dwellings reverberation time depends largely on the furniture and the arrangement of room's interior. It is a question of individual preferences so recommendations rather than requirements are considered. Some countries adopted maximum permitted reverberation time values for stairwells, common areas, common corridors or exit ways with entrances to the apartments, the values are between 1,0s and 1,3s.

3 Relationship between different sound insulation indicators

3.1 Airborne sound insulation

For a specific separating partition in a building the difference between values of basic indicators (R', D_{nT} and D_n) depends on the geometry of considered room system and reverberant conditions in a receiving room. The relationship between airborne sound reduction index R' (the most commonly used) and standardized level difference D_{nT} is expressed by the equation:

$$D_{nT} = R' + 10\log(\frac{V}{S}) - 5dB \tag{1}$$

Where: V is the volume of receiving room, m^3, S is the area of separating partition, m^2.

The values of D_{nT} and R', for this particular partition, are equal when V/S ratio is about 3,2 m. In the case of not staggered rectangular rooms V/S ratio represents height or depth of the receiving room when respectively floor or wall is considered. In multifamily building the height of a storey is about 2,7 m while the depth of a smaller of two adjacent rooms (receiving room) is usually between 2,5 m and 5 m. Then, in the most frequent situations in a building the relationship between above single number quantities is $D_{nT,w} = R'_w \pm 1$ dB for walls, and $D_{nT,w} = R'_w - 0{,}5$ dB for floors.

Relationship between sound reduction index R' and weighted normalized level difference D_n is given by equation (2).

$$D_n = R' + 10\log(\frac{A_0}{S}) \tag{2}$$

Where: S is the area of separating partition, m^2, $A_0 = 10\ m^2$.

The difference ($D_{n,w}$ - R'_w) depends on the area of a separating partition. In the case of small and moderate walls (S= 8-13 m^2) the difference is within the range of ±1dB. For bigger walls and floors the difference is negative and gains e.g. -4 dB for S = 25 m^2

The relationship between values of spectrum adaptation terms is more complicated than for basic indicators. It does not depend on a room arrangement in the building but results from the sound insulation characteristic of a particular partition, depends on its individual structure. Hence, there is no strict relation between values of spectrum adaptation terms for different walls and floors. Although, for certain structural groups of partitions typically used as separating walls in multifamily buildings, the average value of spectrum adaptation terms, as well as the range in which the actual value can be found, can be estimated based on the empirical results. In general, from the structural point of view, in terms of acoustics traditional massive partitions and lightweight frame structures should be considered separately.

Figure 1 shows the relationship between spectrum adaptation terms for massive walls based on laboratory test results achieved for 73 traditional walls of different structure (ceramic bricks, calcium silicate blocks, concrete, light concrete, hollow bricks, multilayer gypsum walls, massive walls with additional lining.). Walls are denoted by numbers, their sound reduction index (R_w) increases with the wall number. The values of spectrum adaptation term C and $C_{50-3150}$ are very close together and the relationship between them is stable for all tested samples. Average values are -1 dB and -2 dB respectively. Spectrum adaptation term C_{tr} is between -2 dB and -7 dB, mean value is about -4 dB.

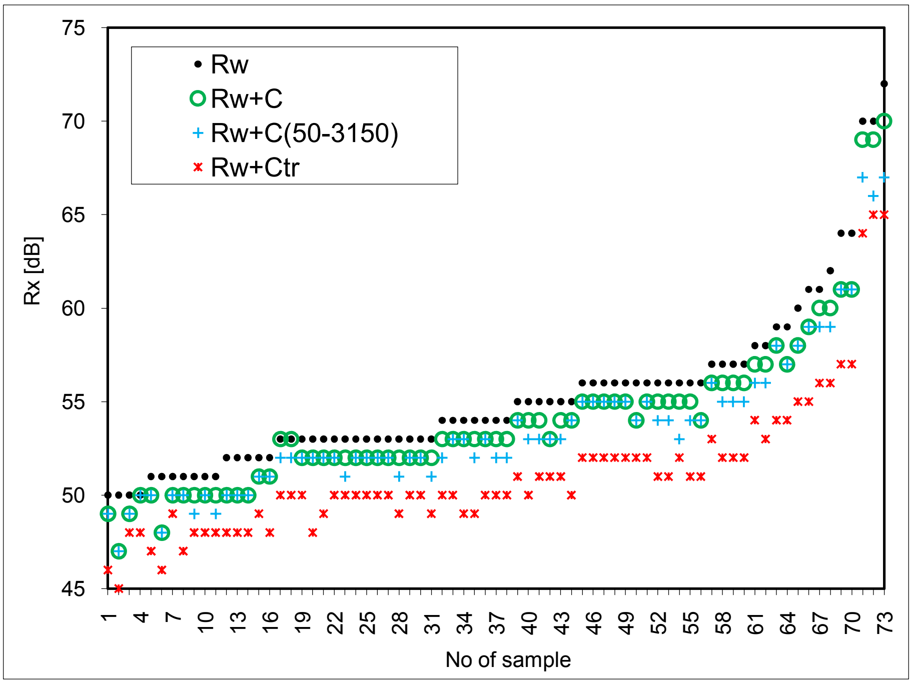

Fig. 1 Relationship between spectrum adaptation terms for massive walls, laboratory test results

In the case of lightweight frame walls the relation between spectrum adaptation terms is different and depends on the type of a wall, particularly on the framework structure and the number of plasterboard panels. Only double framework walls with double plastering have the sound insulation good enough to be used as a separating wall between dwellings in multifamily buildings. The acoustic performance of single framework walls, are not satisfying for such a use so they are not taken into consideration.

Figure 2 shows the results of laboratory test for 75 lightweight walls with double framework and double plastering. Walls, denoted by numbers, have different structure, from simple twin frame 2xC50 to highly insulating walls used in multi-auditoria cinemas. Weighted sound reduction index R_w ranges from 57 dB to 73 dB (walls No 1 to 75). Term C is the most stable, it gains -3 dB on average. $C_{50-3150}$ is lower than for massive walls and it is close to C_{tr} rather than to C, as it was in the case of massive walls. Mean values for the walls considered are -7 dB and -8 dB for $C_{50-3150}$, and C_{tr} respectively. However, the span of the values is much wider than in the case of term C.

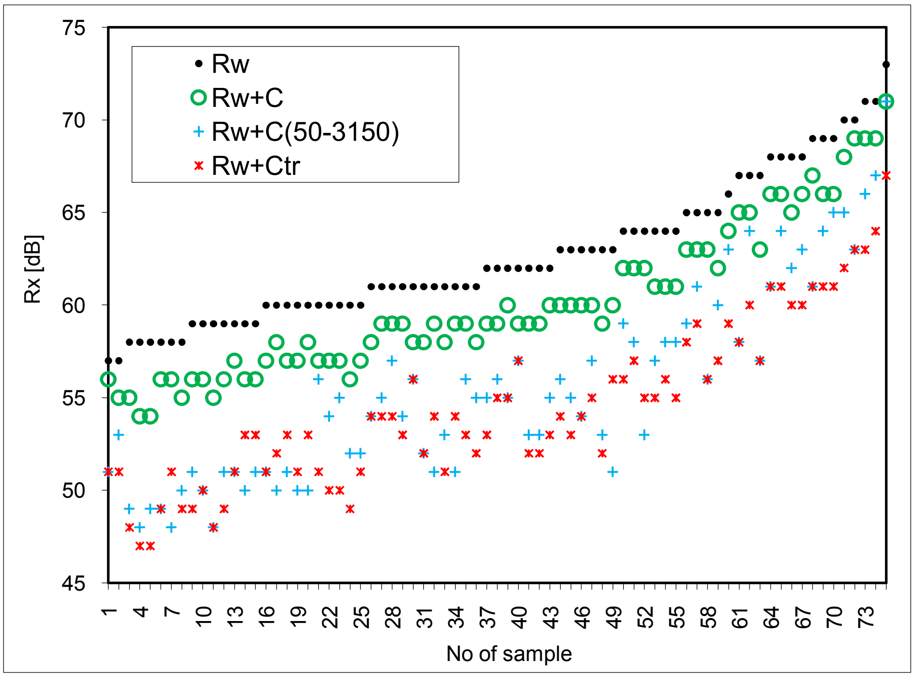

Fig. 2 Relationship between spectrum adaptation terms for lightweight walls, laboratory test results

3.2 Impact sound insulation

Two basic indicators are used for impact sound insulation; standardized and normalized impact sound pressure level denoted by L'_{nT} and L'_{n} respectively. The relationship between them, for the same partition in a building, depends on the volume of the receiving room:

$$L''_{nT} = L'_{n} + 15 - 10\log(V) \quad (3)$$

Both quantities are the same when receiving room volume is about V = 30 m^3. The volume of a room in multifamily building is usually within the range of 25 m^3 to 80 m^3, so the difference (L'_{nT} - L'_{n}) in practice ranges usually from -4 dB to +1 dB, most often it is between - 2 dB and 0 dB, when positive values occur in the case of very small rooms only.

For massive floors, which are the most frequently used in multifamily buildings, the value of term C_I is usually negative and close to 0 dB. Spectrum adaptation term $C_{I,50\text{-}2500}$ tends to be slightly higher than C_I but usually lower than 0 dB. For floors covered with hard tiles it increases to 4 ÷ 5 dB. Single number indicators for lightweight floors are more influenced by their low frequency behaviour so the values of spectrum adaptation terms are usually higher than for massive floors. Although in multifamily buildings lightweight floors are used rather rarely.

4 A concept of uniform acoustic classification scheme

From the perspective of a building performance rating system the variety of acoustical indicators, different limit values and local classification schemes is rather confusing. Final user, and also architect, developer, contractor, etc., is rather interested in the acoustic quality of a building and price related to it than directly in values of different sophisticated acoustical indicators which may be misleading even for professionals e.g. the value of airborne sound reduction index is better if higher while impact sound insulation indicator just opposite. The idea of uniform classification scheme within open manufacturing system is intended to give simple and clear assessment criterion in a similar way as the number of stars describes the category of a hotel.

Sound insulation of the partition system in a building decides on the acoustical quality of the building itself, does not depend on outside noise level or service equipment and its operation conditions. Hence, the sound insulation is the core of proposed scheme. Basic assumption is, that the range of the scheme should embrace all legal values used in Europe, when particular classes should reflect, in a possibly reasonable way, different limit levels in different countries. Such a classification should give to the client the possibility of choice within the performance range covering all European limit levels regardless of building location. On the other hand, the building class may assure that the building meets legal requirements in defined group of European countries, what is particularly important for developers offering their products (buildings) around Europe.

Based on data collected by Rasmussen (2004), and analysis performed by Nurzyński (2007) it is evident, that various indicators in use and their values are so different that single classification scheme based strictly on actual limit values resulting from local regulations is not possible. Nevertheless, these values can be used for determining the range of classification and the span for a single class. Any research on user expectations and individual requirements that allows for diversity around Europe is not known, but it may be assumed that existing local regulations and acoustic requirements are supported by locally made researches and studies then they reflect local situations and in total represents the whole range of expectations and possibilities.

<table>
<tr><th>Group</th><th>Class</th><th>Examples of corresponding local requirements</th></tr>
<tr><td rowspan="3">A</td><td>50 dB</td><td>R'_w = 50 dB (Italy)
$D_{nT,w} + C_{tr}$ = 45 dB (UK)</td></tr>
<tr><td>53 dB</td><td>R'_w = 52 dB (Czech Republic, Hungary, Slovakia, Slovenia)
$R'_w + C$ = 51 dB (Poland)</td></tr>
<tr><td>56 dB</td><td>R'_w = 55 dB (Denmark, Estonia, Finland, Iceland Lithuania, Norway)
$D_{nT,w}$ = 55 dB (Austia)
$D_{nT,w} + C$ = 54 dB (Switzerland)</td></tr>
<tr><td rowspan="3">B</td><td>59 dB</td><td>R'_w = 57 dB (Germany SStII)
$D_{nT,w} + C_{tr}$ = 57 dB (Holland k=2)</td></tr>
<tr><td>62 dB</td><td>$R'_w + C_{50\text{-}3150}$ = 58 dB (Denmark B, Finland B, Iceland B, Norway B)
R'_w = 59 dB (Germany SSt III)</td></tr>
<tr><td>65 dB</td><td>$D_{nT,w} + C$ = 62 dB (Holland k=1)
$R'_w + C_{50\text{-}3150}$ = 63 dB (Denmark A, Finland A, Iceland A, Norway A)</td></tr>
</table>

Fig. 3 Classification scheme matrix, airborne sound insulation

For airborne sound insulation, when taking into account minimum requirements (mandatory) and local classification schemes (not mandatory), the limit values used in various European countries differ within the range of about 15 dB (sic), between R'_w=50 dB and $R'_w + C_{50\text{-}3150}$ = 63 dB. The frame proposed for airborne sound insulation classification is shown in figure 3. The range of part A embraces all minimum requirements, when part B contains higher, not mandatory limit values defined by local classification schemes. Single number quantities were grouped into six classes, beginning from R'_w = 50 dB with 3 dB step. Airborne sound reduction index R'_w was taken as a basis for the classification as it is the most frequently used in Europe and equivalent to STC used in the US.

Group	Class	Examples of corresponding local requirements
A	61 dB	$L'_{n,w}$ = 63 dB (Italy) $L'_{nT,w}$ = 62 -65 dB (Spain, UK)
	57 dB	$L'_{n,w}$ = 58 dB (Czech Republic, Poland, Slovakia, Slovenia) $L'_{nT,w}$ = 58 dB (Belgium)
	53 dB	$L'_{n,w}$ = 53 dB (Denmark, Estonia, Finland, Germany, Iceland, Lithuania, Norway) $L'_{nT,w} + C_I$ = 53 dB (Holland)
B	49 dB	$L'_{nT,w}$ = 48 dB (Austria) $L'_{nT,w} + C_I$ = 50 dB (Switzerland)
		$L'_{n,w} + C_{I,50\text{-}2500}$ = 52 dB (Sweden B) $L'_{nT,w}$ = 52 dB (France QLAC)
	44 dB	$L'_{n,w} + C_{I,50\text{-}2500}$ = 48 dB (Denmark B, Iceland B, Norway B) $L'_{n,w}$ = 46 dB (Germany (SSt II)
	39 dB	$L'_{n,w}$ = 39 dB (Germany SStIII) $L'_{n,w} + C_{I,50\text{-}2500}$ = 43 dB (Denmark A, Finland A, Iceland A, Norway A)

Fig. 4 Classification scheme matrix, impact sound insulation

In a parallel way the limit values for impact sound insulation, mandatory and voluntary, are arranged in figure 4. Weighted normalized impact sound pressure level $L'_{n,w}$ is adopted as a basic quantity with 4 dB step in group A, and 5 dB step in group B. The situation is more complicated because existing minimum requirements are more diverse. Group A overlaps with group B representing local classification schemes. Part A includes all minimum requirements but Austria and Switzerland which are very strict on impact sound insulation. Part B embraces all local classification schemes and minimum requirements for these two countries.

Airborne and impact values arranged into classes (figure 3 and 4) can be combined into one classification scheme (figure 5). Indicators used as a basis for both classification frames, R'_w and $L'_{n,w}$, are of symbolical meaning as the other single number quantities in use may be put into adequate class taking into account relationship between them (Nurzyński 2007). In this way the scheme may contain hidden matrix with all minimum values of quantities used in different countries organized in classes (figure 3 and 4).

In practice the values of all single number indicators in use can be determined for a specific building based on field measurements (one measurement gives all quantities). In the case of strictly catalogued industrialized building system, the compliance with a performance standard of a specific class may be demonstrated by pre-completion on site acoustic testing or by using acoustic details.

The frame of classification scheme is constructed on the basis of sound insulation requirements. Adequate values of noise level may be attached to each class as well as the reverberation time limits.

Class	Sound insulation descriptor, dB	
	Airborne	**Impact**
A1	50	61
A2	53	57
A3	56	53
B1	59	49
B2	62	44
B3	65	39

Fig. 5 Frame values for uniform classification scheme

5 Conclusions

Local acoustic regulations and classification schemes are based on locally made research and studies so it may be assumed they reflect local expectations, requirements, possibilities, cultural habits etc. Any research on user expectations and individual requirements taking into consideration diversity around Europe is not known. Thus the limit values and local classification schemes used in different countries may be used for determining the frame of the uniform scheme and the span for a single class.

Proposed scheme embraces all values of sound insulation indicators used in Europe, when particular classes reflect different level of existing requirements. It gives to the client the possibility of choice within the performance range covering all European limit values. Adequate values of noise level may be attached to each class.

The paper presents just a concept of the uniform acoustic classification scheme designed for use within open building system defined in the frame of Integrated Project ManuBuild. It shows the possible way toward harmonization of acoustic criteria and requirements in Europe and how to switch from various acoustic indicators considered separately to coherent assessment tool for the whole building.

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