Model-based assessment scheme for acoustic quality classes in buildings

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Introduction

The acoustic performance of dwellings was first specified in the Netherlands in the standard NEN 1070 [1] as minimum requirements in 1962. This standard was amended in 1976; the assessment of impact sound was changed completely, following a study to assess the walking sound by people better [2], and all quantities were standardized to a reverberation time of 0,5 s, that had shown in a social survey to improve the correlation with annoyance significantly [3].

In the nineties these requirements were largely incorporated in legal minimum requirements, which opened the possibilities to renew the standard completely. No longer only minimum requirements should be specified but different quality classes and application to other buildings than dwellings should be included. In order to reach this goal it was decided not to start from the existing standard, being partly based on insufficiently based data, discussions and compromises, but to develop first a general assessment model for the acoustic quality for all relevant aspects of buildings. From this different quality levels could be derived for dwellings and buildings with other functions.

For dwellings it proved at the end that the 'old' minimum requirements corresponded reasonably with a quality class, but the requirement for impact sound needed to be increased and more differentiation should be applied to the sound levels of various sorts of equipment.

Assessment model

The subjective assessment of sound levels in the living and working environment in a building will depend on several aspects, like the type of sound source, the possibilities to influence its strength, the received sound level, spectrum shape, long term and short term level variations, privacy feeling, personal circumstances etc. Several of these aspects can only be taken into account globally as an average (or safe average) for all people in 'normal' circumstances.

It is assumed that the assessment of the situation first of all depends on the received sound level due to the various sources. Such a level is adequately described by the A-weighted level and, as indicated in the introduction, a standardization to the reverberation time is appropriate. Of course this level is the actual sound level as caused by a source or the sound level that would be experienced normally in the given situation. For equipment noise it is the actual sound level. For other sources - like the road traffic, the neighbours radio or the walking of the neighbours children - the sound level is based on an assumed typical behaviour of the 'source' (representative source, source strength, spectrum shape etc.) and the actual sound transmission in the building. From this reasoning it follows that the sound transmission is best described by quantities like D_{nT} and L_{nT}, rated in accordance to the alternative ISO 717-system with the appropriate source spectrum [4]: $D_{nT,A}$ (=$D_{nT,w}$+C), $D_{nT,Atr}$ (=$D_{nT,w}$+C_{tr}) and $L_{nT,A}$(=$L_{nT,w}$+C_I).

The assessment of the received level will be based on a comparison with an acceptable (reference) sound level, leading to the rating level: a relative measure. This **reference level** can be an allowable level based on the type of functions that are to be conducted in the buildings, like reading, resting, working. For dwellings it will be the natural residual level (background level) as is natural or typical for the surroundings of the building, like a city centre or a rural area. For dwellings in residential area a level of 25 dB(A) seems to be an appropriate average value. The premise is in that case that for a sound to be potentially disturbing it must be heard in the first place. For a sound to be detectable the peaks in the sound level (i.e. time integration 'S') should be at least comparable to the residual sound level (dynamics). It than depends on the type of source, its representative working conditions - and whether the source level can be influenced or not - what level people will tolerate before they really get annoyed (tolerance). Representative conditions do normally occur during the regular louder working periods, in other words the periods when the tolerance is reduced to 0 dB. The peak level can also be deduced from the equivalent level and knowledge of the typical dynamics of the sound of a specific source. While the source strength at such moments is important for the level of the requirement, the spectrum at that time is relevant for the determination of the single number rating.

The rating level is than expressed as a quality number that has a direct relation to the subjective rating (annoyance score) by people. The combination of all quality numbers (all relevant rooms and all relevant acoustic aspects) leads to a classification of the dwelling as a whole. Since equal quality numbers according to this model indicate equal annoyance, the worse number dominates the assessment of the dwelling as a whole. The model is illustrated in Figure 1.

The rating level of a specific source in a specific situation is thus determined by the difference between the received sound level (L_{pAeq} or $L_{pAeq,source}$ - transmission) and the reference sound level (L_{ref}), taking into account the dynamics of the sound ($C_{dynamics}$) and the acceptance of the specific source ($C_{tolerance}$). The received sound level is directly or via the sound transmission related to the performance quantity for that specific type of source. For airborne sound as example the rating level L_r can be written with equation (1) using the sound transmission $D_{nT,A}$.

$$L_r = L_{p,Aeq,neighbour} + C_{dynamic} - D_{nT,A} - C_{tolerance} - L_{ref} \quad \text{[dB]} \qquad (1)$$

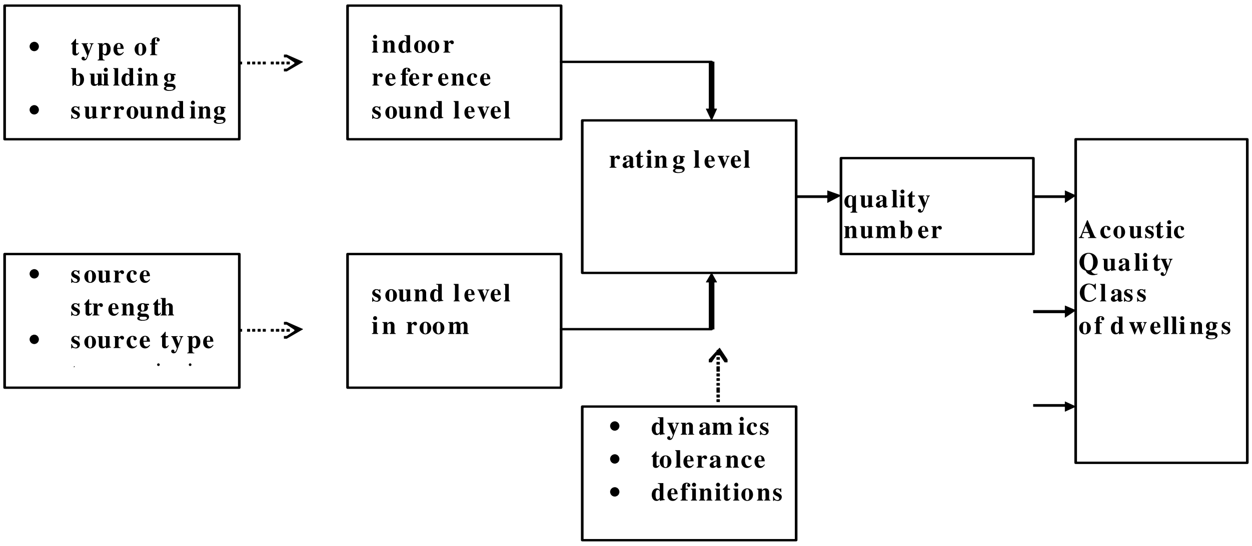

Figure 1: Illustration of the assessment model with relevant aspects for the rating system for buildings. Combining the quality numbers for each aspect and each situation in a dwelling results in the Acoustic Quality Class of the dwelling

To be able to apply this model the various terms like the source levels, the dynamics and the tolerance need to be known. Not too much information of that kind is available, but indications can be found from some studies, for instance [1] and [5].

The representative **source levels** for airborne sound could be based on an earlier study showing that 70 dB(A) on average was the preferred listening level, though depending on the item and the person the level could be up to 10 dB higher. On the other hand the tolerance for this type of sound is also about 10 dB. Figure 2 gives an example of a social survey depicting the difference in people hearing and being disturbed by their neighbours. So as representative airborne source level 70 dB(A) was chosen with the tolerance set to zero dB. The dynamics of spoken word and music is further set at 12 dB, as followed from many sources.

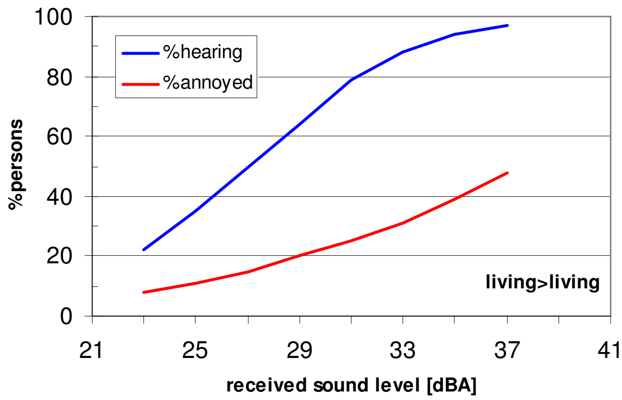

Figure 2: Percentage of people hearing and being annoyed by their neighbours in the living room as function of the received sound level (=70+12-D_{nTA}).

For impact sound the sound levels of the tapping machine can be translated in an equivalent way to sound levels due to walking [2], taking into account the dynamics setting the tolerance to zero dB also, the level difference is 23 dB(A).

For outdoor sources and sound levels due to service equipment the same approach can be applied.

The **quality assessment** of the rating level can be deduced from social surveys. But social surveys with respect to sound in dwellings or other buildings have not been performed on a large scale. In order to cover all aspects an effort has been made to collect and combine various results, both from different countries as from different periods. In these studies normally very different methods have been applied in the way the results were gathered and expressed. For our purpose these results were all converted into a 7-point assessment scale as given in [4]. Figure 3 gives an example for the airborne sound transmission between dwellings. As can be seen the relation can reasonable well be represented by a linear relation. This showed to be the case also for other sound sources and for the rating level that relation was about the same for all sources, so this type of score is a good bases for acoustic quality classes.

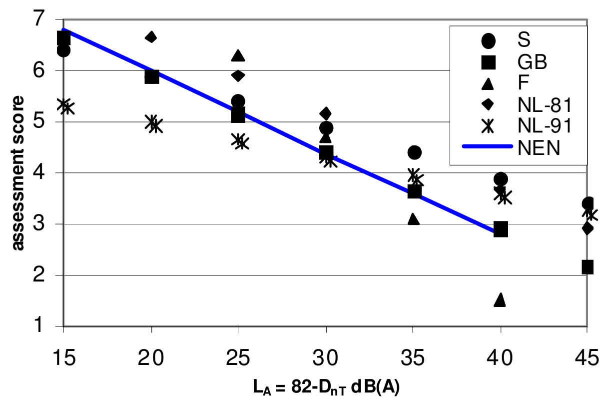

Figure 3: Global relation between the constructed received airborne sound level and the subjective quality score (from 1= very good to 7=very bad), based on some European social surveys.

For the renewed Dutch standard NEN 1070 [6] it was decided to uses five quality classes leading in most cases to steps of 5 dB between classes. In this way the range around the current state of the art was covered from socially unacceptable quality (10 dB less) to about the economically achievable maximum quality (10 dB better).

The same data can also be presented as the percentage of people (severely) **annoyed** by the sound sources, for instance by taking the people with the worst 2 out of 7 as their assessment. Some of the gathered results have been collected in this way in Figure 4 for various sources types and situations. The received sound levels have not yet been adjust for dynamics and tolerance, hence the rather large spread. But if we do so the results group around the line indicated as being the typical relation between sound level and percentage being annoyed.

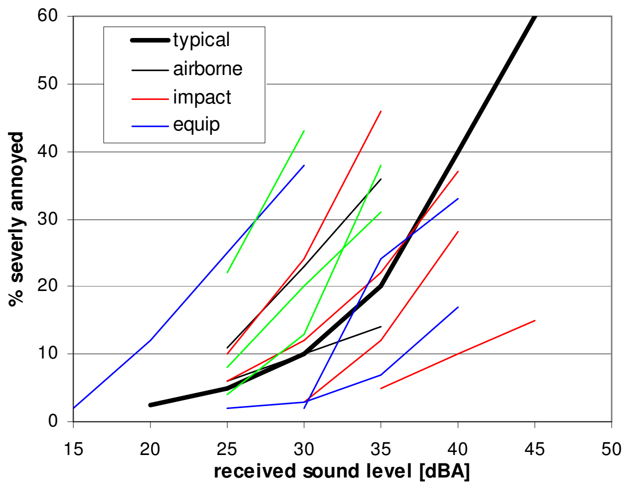

Figure 4: Percentage of people severly annoyed as function of received sound level for various sound sources (airborne, impact, equipment) and situations. typelobal relation between the constructed received airborne sound level and the subjective quality score (from 1= very good to 7=very bad), based on some European social surveys.

Looking at 5 dB classes we see steps of 20% in the linear range of that typical line changing to halving the percentages for each 5 dB step at the lower sound levels (better quality). That 20% per 5 dB has also been reported by Rindel [7].

The Dutch standard NEN 1070

Using the assessment model as presented the current Dutch standard NEN 1070 specifies the requirements for dwellings in five quality classes. For each aspect and situation the quality can be given as a quality number *k*; for a dwelling as a whole the lowest quality for all rooms and all soud sources determines the quality class then indicated as a roman number: I (the best) till IV (the worst). Also for other types of building (i.e. schools, hospitals, offices) the requirements for different quality classes are specified, though more globally since for those buildings the situations vary too much to specify such classes in detail. In Table 1, as an example, the requirements between dwellings in the standard are given for the two quality classes III ('sufficient') and II ('good'). The requirements for noise due to the service equipment varies somewhat for the different systems and installations such as elevators, heating, ventilation, water supply and waste water systems, hence a range is indicated.

Sources	**Quantity**	**Quality Class**	
		III	**II**
Airborne sound	$D_{nT,A} \geq$	52	57
Impact sound	$L_{nT,A} \leq$	53	48
Outdoor sound	$D_{2m,nT,Atr} \geq$	23	28
Equipment sound	$L_{pASmax,nT} \leq$	30-35	25-30

Table 1: Requirements for the acoustic performance between dwellings for two quality classes.

The legal minimum requirements in the Netherlands corresponded globally with quality class III except for impact sound. Since 2003 that legal requirement has been adjusted to come in line with the standard (though still traditional single number ratings are used in stead of the ones from NEN 1070). The requirements for outdoor sound reduction are further related to the exterior sound impact. In the table the minimum is given (for a ventilated façade); the reduction should be increased with the same amount as the outdoor sound level exceeds 50 dB(A).

The required class for a certain acoustic comfort level will depend not only on the acoustic class of the building but also on the characteristic residual sound level in the environment of the building and probably the sound reduction by the facade of the building. However, at this moment insufficient data is available to quantify these effects. Thus it is only recommended to require a higher class in very quiet surroundings and to consider to accept a somewhat lower class in very noisy areas like a city centre.

In order to give also an understandable meaning to the acoustic values as in Table 1 indication is given in the standard of the corresponding amount of protection against noises and a global indication of the % annoyed people. These indications are given in Table 2. This should help the non-acousticians to understand the classes and make the appropriate choices.

Comparison with other countries

Classification schemes for the acoustic quality of buildings have been developped elsewere too. Rasmussen has done several efforts to collect information on regulations and classifications systems throughout Europe [8]. A handicap in comparing data is largely the use of sometimes very different quantities to express the acoustic performance, some well related, others less well related. To show such a comparison between the Dutch standards and some others a selection have been made of some Scandinavian classifications schemes and a recent German proposal. For airborne sound these requirements are mainly expressed as R'_w, but sometimes also including lower frequencies by applying $C_{50\text{-}3150}$. For the comparison only airborne sound insulation is considered and these values are translate to $D_{nT,A}$ through $D_{nT,A} \approx R'_w$ and $D_{nT,A} \approx R'_w + C_{50\text{-}3150} + 3$. The result is given in Figure 5.

Quality class	**Description of situation**	***% annoyed (global)***
I	A quiet atmosphere with a high level of protection against intruding sound. Sounds from outside are barely detectable. Very loud speech is generally not intelligible, normal speech and music not detectable; loud music and parties are detectable but hardly annoying. Walking sounds are hardly detectable and equipment noise only seldom disturbing.	< 5%
II	Under normal circumstances a good protection against intruding noise without too much restriction of the behaviour of the occupants. Normal speech not detectable, loud speech and music sometimes detectable but not intelligible. Very loud speech and music, parties, clearly audible but speech not intelligible. Walking sounds generally not disturbingly audible and equipment noise only sometimes disturbing.	5% - 10%
III	Protection against unbearable disturbance under normal behaviour of the occupants, bearing in minds the neighbours. Speech sometimes detectable but not intelligible. Very loud speech intelligible, loud music clearly audible. Walking sounds sometimes disturbingly audible. Unbearable disturbance by equipment noise generally avoided.	10% - 25%
IV	Regularly disturbance by noise, even in case of comparable behaviour of occupants, adjusted to neighbours. Speech and music often audible. Very loud speech well intelligible and loud music disturbing. Walking sounds often disturbing and regularly disturbance by equipment noise generally.	25% - 50%
V	In fact no protection is offered against intruding sounds. Normal speech is intelligible. Music, loud speech, walking sounds and equipment sound very often disturbing	> 50%

Table 2: Requirements for the acoustic performance between dwellings for two quality classes.

NL		V	V	V	V	V	IV	IV	IV	IV	IV	III	III	III	III	III	II	II	II	II	II	I	I	I	I	I						
DK/N/I										D	D	D	D	D	C	C	C	C	C	C	B	B	B	B	B	A	A	A	A	A		
S									D	D	D	D	D	C	C	C	C	C	C	B	B	B	B	A	A	A	A					
D							F	F	F	E	E	E	D	D	D	D	C	C	C	C	C	B	B	B	B	B	A	A	A	A	A	A*
D_{nTA}	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72

Figure 5: Comparison of the classification system in some countries (Denmark, Norway, Iceland, Sweden, Germany and the Netherlands) using the proposed colouring of the 7 classes DEGA-proposal [9].

Besides the differences in indication (letters and numbers) of the classes there are still some aspects to solve befor a European schema could be developped. And this is surely is even more so considering impact sound and outdoor sound.

Conclusions

A model for the assessment of the acoustic quality in buildings have been presented that has formed the basis for the Dutch standard NEN 1070 from 1999. Deriving the requirements from such a model assures that the various aspects are now treated in a more balanced way than in the past, but it was reassuring to see that the so specified requirements for an 'average' quality class showed a fair correspondence with existing requirements.

Comparing some European schemes or proposal for quality classes show clear differences. However, it is likely that the basic cause for this is the variation in the type of quantities – and frequency range – used for expressing the acoustic performance. After agreeing on uniforming that, agreeing on classes and numbers should be much easier.

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