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AIRBORNE SOUND INSULATION IN DWELLINGS AND ITS SUBJECTIVE ESTIMATION

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Abstract

The sound insulation in buildings has an important bearing on the comfort, health and general amenity of the residents. This is particularly true of the elements separating dwelling units from an adjoining dwelling unit. There are an increasing number of complaints from occupants about sound levels being transmitted through the walls and floors. The quality of sound insulation in buildings is generally described as a single number rating of sound insulation. Since the early 1950s and 1960s, where the main body of standards of sound insulation in dwellings are originated, there have been considerable improvements in living standards associated with an increased noise level produced in the room. Performance requirements specify that walls and floors must provide insulation against the transmission of airborne sound that is sufficient to prevent illness or loss of amenity to occupants. The rating systems are lacking on the ability to quantify subjectively related disturbances between dwellings due to audible sounds perceived from neighbour's activities. There is growing concern that standards governing sound insulation between dwellings are not meeting consumer expectations. Due to raised comfort demands concerning the airborne sound insulation in dwellings for example, it is not sufficient to avoid intelligibility listening through walls but to avoid recognition of transmitted sounds in general. A comparison of measured sound insulation with the absolute threshold of hearing endow with details judging the quality of the real acoustical comfort of dwellings. A comparison between the standardised sound level difference and the hearing threshold depending upon background noise level is proposed.

INTRODUCTION

The principal objective of any legal requirements in relation to sound transmission is to safeguard occupants from illness and loss of amenity as a result of undue sound being transmitted between dwellings, from common spaces or other classes in a building to dwellings. This scheme of an “objective safeguard”, by contrast, is not considered to be essential in every day life due to the increasing demand of privacy and quiet. There is growing concern in general that the current standard of sound insulation between dwellings is not meeting consumer expectations. This concern is supported by evidence of an increasing number of complaints from occupants about high sound levels being transmitted through the walls and floors and from service pipes. The reason for complaining may that current legal requirements are inadequate and require improvement. There has been a significant rise in the number of complaints in recent years, particularly in Germany, that demonstrate that many people are dissatisfied with the minimum level of sound insulation currently provided by the legal regulation, e.g. in Germany the DIN 4109. Specifying the precise extent of the noise problem is difficult because the nature of annoyance and loss of amenity due to noise intrusion is inherently subjective. Since the acoustic performance of a residential building has an important bearing on the comfort, health and general amenity of the residents, it is of general interest to specify sound insulation more precisely, e.g. in response to consumer demands for good acoustic performance. It is no general use to improve the privacy of people in residential buildings by just increasing the sound insulating performance of walls and floors between dwellings without considering the effect of human hearing, background noise and sound insulation performance. The wish after quiet and ease has a high meaning for inhabitant and user of buildings. That is, why building acoustics is gaining more and more importance in our every day life. Due to the need having a quite atmosphere in our dwellings, flats or houses, noise from neighbours is becoming even more important than minimizing warmth losses, i.e. energy savings. The problem to be considered is the transmission of noise from one dwelling unit to another. Due to raised comfort demands concerning the airborne sound insulation in dwellings, as well as in flats and houses etc., it is not sufficient to avoid intelligibility listening through walls, or to safeguard occupants from illness, but to avoid recognition of transmitted sounds in general. Especially due to the results reported in [1] of the LARES-survey, initiated by the European Housing and Health task force of the world health organisation (WHO), it is recommended to introduce in a more distinct way the subjective related assessment of sound insulation in buildings. Within the context of the LARES-survey, noise annoyance within the everyday living environment was collected and evaluated in connection with medically diagnosed illnesses. Adults who indicated chronically strong annoyance due to neighbourhood noise were found to have an increased health risk in the cardiovascular system, the movement apparatus as well as depression and migraine[1]. Due to the complexity of the issues involved in determining acceptable sound insulation performance, it is proposed in this paper a first investigation of the subjective estimation of various sound insulations between dwellings depending upon background noise level.

THE CONCEPT OF RATING

The quality of sound insulation in buildings is generally described as a single number rating of sound insulation. The difference in sound levels from one side of a wall to the other indicates the sound transmitted loss through the wall. Acoustic tests relate sound loss through a wall at various frequencies then average the results to provide a single absolute value number. This rating system is necessary if one wishes to compare other wall systems with a specific wall design. The methods for measuring the airborne sound insulation of building elements and in buildings have been standardised in the international standard EN ISO 140-4. The rating of the airborne sound insulation is regulated in the international standard EN ISO 717 [2]. The Weighted Standardised Level Difference ($D_{nT,w}$) and the Spectrum Adaptation Term (C) are determined on the basis of the A-weighted sound level differences and on the basis of a standardised spectrum for the sound level in the building interior (indoor noise) according to EN ISO 717. The Weighted Standardised Level Difference ($D_{nT,w}$), or the Weighted Sound Reduction Index (R_w), etc., are single-figure rating schemes intended to rate the acoustical performance of a partition element under typical conditions involving dwelling separation. The higher the value of either rating, the better the sound insulation. Thus, the rating is intended to correlate with subjective impressions of the sound insulation provided against the sound of speech, radio, television, music and similar sources of noise characteristic of dwellings. In applications involving noise spectra that differ markedly from those referred to above (for example, heavy machinery, power transformers, aircraft noise, motor vehicle noise), the R_w and $D_{nT,w}$ are of limited use. Generally, in such applications it is desirable to consider explicitly the noise spectra and the insulation requirements. The method of transforming the frequency-dependent sound insulation in single number ratings may be criticised for the reason that the reference curve is not always appropriate for all constructions. In the rating scheme of ISO 717, for instance, frequencies below 100 Hz and above 3150 Hz are not taken into account to establish the single value, like R'_w or $D_{nT,w}$ etc. Therefore, it is most likely that low frequency noise is not correctly represented by a single number figure. It is thus possible that very different sound insulation curves come up with the same single number ratings. Also there is no means to recall the frequency dependent shape of the insulation from the single number rating, because the necessary information was lost during the transformation [3]. The absolute value used in this preliminary field investigation is the standardised sound level difference D_{nT} between two rooms. Since it is well known that a single number quantity is not able to specify an acoustic comfort in dwellings [4] [5] it is proposed to do a comparison on the basis of the spectral corrected standardised sound level difference ($D_{nT,w} + C$) and the absolute hearing threshold [6]. We do need some sort of subjective unit of loudness in order to judge the human reaction to loudness of sound more close to reality. The phon is the unit of loudness level that is tied to sound-pressure level at 1 kHz. In an attempt to account for human hearing sensitivity in a standardised way the A-weighting characteristic is most widely used, and though originally intended for low-level sounds, it is commonly applied to higher sound levels as well.

ACCOUNTING FOR AUDIBILITY OF SOUNDS

The problem of judging the human reaction to loudness of sound is complicated by the problem of measuring audibility of sounds due to the nonlinearity of human hearing. The frequency dependence of human hearing is described originally by the Fletcher-Munson Curves (1933) and later on by Robinson-Dadson (1956). Curves defining combinations of pure tones in terms of frequency and sound pressure level, which are perceived as equally loud, express a fundamental property of the human auditory system and are of basic importance in the field of psychoacoustics [7]. The threshold of hearing under diffuse-field listening conditions were specified in ISO 389-7:2003(E) [8]. Fig. 1 shows the hearing threshold under diffuse-field listening conditions as provided by the International Standard ISO 389-7.

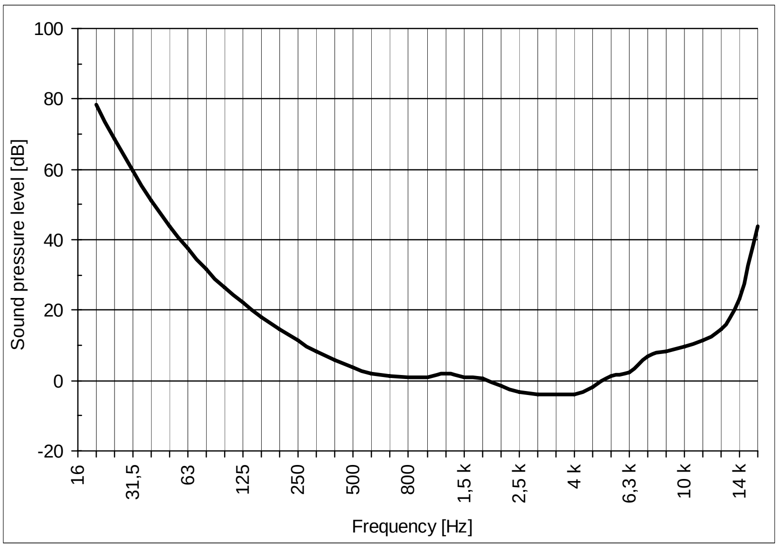

Figure 1 – The Absolute Threshold of Hearing [8]

CASE STUDY

To specify the sound insulation between dwellings it is generally accepted that a single figure index is not sufficient and is regularly misleading. Due to the single rating concept 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 cases the construction consists of a concrete floor base of thickness 180 mm with a floating floor and for the cases 1 and 2 of four flanking plastered masonry walls.

Case 1: Two external masonry walls have thickness of 365 mm and one internal masonry wall has 115 mm and one 175 mm. The volume density of the masonry walls is 700 kg/m^3.

Case 2: Three external masonry walls have thickness of 175 mm with a volume density of 1400 kg/m³ and one internal masonry wall has a thickness of 175 mm with a volume density of 1200 kg/m³.

Case 3: In the receiving room are 3 flanking plastered masonry wall and one internal framed plasterboard wall. Two external masonry walls have thickness of 365 mm and one internal masonry wall 240 mm. The volume density of the walls is 650 kg/m^3.

Case 4: An additional independent free-standing panel consisting of 2 layers of plasterboard with staggered joints and mineral wool in the cavity were built on the inner side of the external and one internal walls in the source room to reduce flanking transmission.

Case 5: Same as Case 4 with additional independent panels at the two external walls in the receiving room.

Case 6: Same as Case 5, adding 2 independent panels, i.e. all 4 walls in the source room have independent panels.

Table I - Measured standardised sound level difference $D_{nT,w}$ with adaptation term C

Case	Standardised sound level difference $D_{nT,w} + C$	Weighted Sound Reduction Index $R'_w + C$
1	50 – 1 dB	51 – 1 dB
2	54 - 0 dB	52 – 0 dB
3	55 – 1 dB	52 – 1 dB
4	58 – 0 dB	56 – 1 dB
5	62 – 1 dB	60 – 2 dB
6	65 – 2 dB	62 – 2 dB

From Table I it is seen, that the $D_{nT,w}$ is raised form 50 dB up to 65 dB. In all Cases the sound insulation was claimed to be not sufficient. Subjective tests result, that a spoken word of a raised voice was audible but not in any Case intelligible. This was true especially for Case 4, 5 and 6. In order to investigate the resulting sound transmission from measurement it is convenient to define a kind of level difference of a speech sound pressure level and the standardised sound level difference (L_{Speech}-D_{nT}). Comparing this difference level of Case 1 with the absolute threshold of hearing reveals Fig. 2, were the graph of calculated level difference for a typical sound pressure level of a raised voice ($L_{Speech} = 78\ dB(A)$) and the measured standardised sound level difference is compared with the graph of the absolute threshold of hearing.

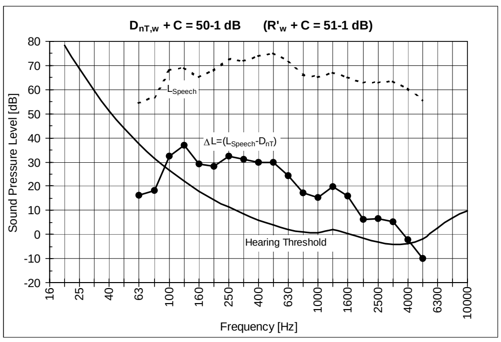

Fig. 2 shows the speech level (L_{Speech}) as dashed line, and the difference level (ΔL) as a solid line with full dots. The shown graph depict results in a frequency range from 63 Hz up to 5 kHz. The hearing threshold presented as a solid line is shown in a frequency range from 20 Hz up to 10 kHz. Depict are results for Case 1.

Figure 2 –Difference level and speech level vs. hearing threshold, Case 1

From Fig. 2 it is seen that the frequency range of hearing is from 100 Hz up to 4 kHz and that the level difference has save distance to the absolute threshold of hearing in a broad frequency range. Introducing additional the background noise level (*BGN*) one may observe the range of masking. This is shown in Fig. 3 where the background noise level is additional introduced in Fig. 2 for comparison reason.

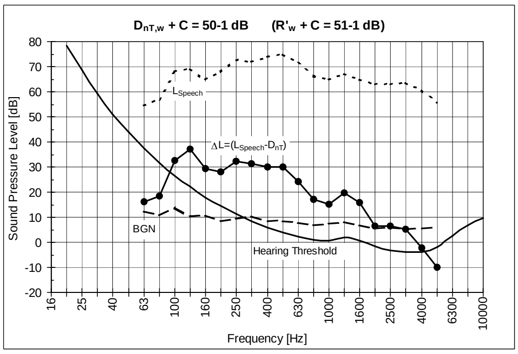

Fig. 3 shows the results for Case 1 if the background noise level is additional considered in order to illustrate the restricted “hearing area” due to masking background noise level above the absolute hearing threshold. The frequency range of hearing is shortened to a region at about 100 Hz up to 2 kHz compared to Fig. 2.

Figure 3 –Difference level and speech level vs. hearing threshold, Case 1

In order to investigate the subjective related measure for the revealed level differences compared with the background noise level, in Fig. 4 and Fig. 5, results are shown for the calculated loudness level (L_N). Fig. 4 and Fig. 5 reveals the comparison with background noise level (*BGN*) and sound level difference (L_{Speech}-D_{nT}) for two cases, namely Case 1 and Case 6, respectively.

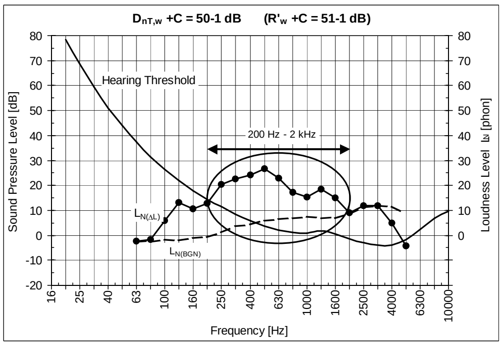

Fig. 4 shows the results for Case 1 if the level difference and the masking background noise level are converted into loudness level. The comparison to the absolute hearing threshold and the background noise level reveals a smaller “hearing area” than just comparing sound levels as shown in Fig. 3.

Figure 4 – Loudness level vs. hearing threshold – Case 1

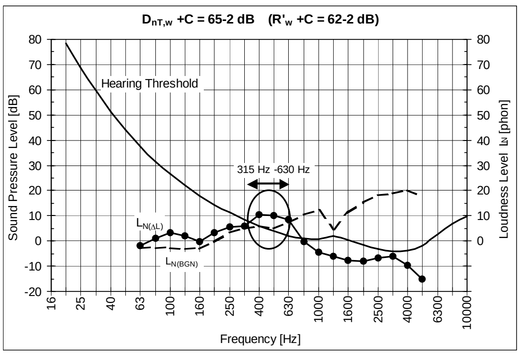

Fig. 5 shows the results for Case 6 in analogy of Fig. 4. From comparison it is seen that the frequency range above hearing threshold becomes smaller for the subjective related loudness level above background noise. The cutback of frequency range is of about 3 octaves, and the decrease of loudness level is of about 15 phons.

Figure 5 – Loudness level vs. hearing threshold – Case 6

From comparison of Fig. 4 and Fig. 5, respectively, it becomes clear how the subjective perception of the airborne sound insulation is related to the loudness level above background noise $L_{N(BGN)}$.

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.

RESULTS

From the investigation it was found in a first step, that there is a gap between a physical and a subjectively assessed sound insulation. The standard rating systems lack on the ability to quantify subjectively related disturbances between dwellings due to audible sounds perceived from neighbour's activities. A comparison of measured sound insulation with the absolute threshold of hearing endow with details judging the quality of the real acoustical comfort of dwellings. Since in most cases A-weighting is satisfactory for ranking noise in approximately the same way as it is subjectively heard, it is proposed to use the spectral corrected standardised sound level difference ($D_{nT,w}$ + C) in decibel calculated in accordance with the EN ISO 717 for assessment reasons. It seems feasible to prompt, that the real acoustical comfort subjectively correlates better with a spectral corrected standardised sound level difference as specified in Table II, as it does without. In order to categorize an appropriate sound insulation 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 perceived sound level. It is proposed from a subjective point of view a $D_{nT,w} + C \geq 58$ dB for reasonable acoustical comfort in dwellings.

CONCLUSIONS

In this paper a very preliminary field investigation towards the development of a kind of rating system was reported. It has been presumed, that the quality of airborne sound insulation in buildings described as a single number rating of sound insulation is inadequate and requires improvement due to a significant difference between the standard rating of sound insulation and its subjective assessment. Since a subjective experience of noise stress can lead to regulation diseases as reported for example in [1], it is assumed that a more specific requirement is needed to quantify sound insulation to safeguard occupants from illness. 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. However, more extensive testing and investigation is required to make quantitative predictions from the point of neighbourhood noise and its correlation to morbidity. It goes without saying that this paper presents only a very preliminary step towards the development of the kind of rating it treats. All of the results, however, ought to be evaluated in a more extensively way, particularly the procedure of the listening tests. It would be desirable to find a more sophisticated rating scheme comparable to the spectrum adaptation terms C according to ISO 717, which allows the building engineer to make predictions not only about speech privacy, but also to avoid noise induced annoyance. The next step for future study is to improve or modify the calculation of a single number rating scheme.

REFERENCES

[1] H. Niemann, C. Maschke, K. Hecht, M. Huber, "Nachbarschaftslärm bedingte Belästigung und Erkrankungsrisiko - Ergebnisse des Paneuropäischen LARES-Survey" (in German), Fortschritte der Akustik, DAGA 2005, Munich, Germany

[2] European Standard EN ISO 717-1 (1996), "Acoustics – Rating of sound insulation in buildings and of building elements – Part 1: Airborne sound insulation"

[3] R. Thaden, "Investigation on the relation between single number ratings and speech intelligibility", International Congress and Exhibition on Noise Control Engineering – INTER-NOISE 2001, The Hague, The Netherlands

[4] M. Vorländer, R. Thaden, "Auralisation of Airborne Sound Insulation in Buildings", ACUSTICA united with acta acustica, Vol. 86, No. 1, pp. 70-76 (2000)

[5] K. Joiko, V. Bormann, W. Kraak, "Durchhören von Sprache bei Leichtbauwänden" (in German), Z. Lärmbekämpf., Vol. 49, No. 3, pp.79-85 (2002)

[6] R. O. Neubauer, "Subjective Estimation of Airborne Sound Insulation in Buildings and How to Quantify the Real Acoustical Comfort of Dwellings.", 51. OSA Open Seminar on Acoustic, Danzig, Poland (2004)

[7] E. Zwicker, H. Fastl, *Psychoacoustics. Facts and Models. (*2nd Edition, Springer, Berlin 1999, pp. 203 - 205)

[8] International Standard ISO 389-7 (E) (2003), "Acoustics – Reference zero for the calibration of audiometric equipment – Part 7: Reference threshold of hearing under free-field and diffuse-field listening conditions"