Subjective Evaluation of Airborne Sound Insulation below 100 Hz

Reinhard O. Neubauer[1], Jian Kang[2]

[1] *University of Sheffield, Sheffield S10 2TN, UK, Email: r.neubauer@sheffield.ac.uk*
[2] *University of Sheffield, Sheffield S10 2TN, UK, Email: j.kang@sheffield.ac.uk*

Introduction

Based on the demand to have a better sound insulation in subjective regards, it is necessary to have an extended frequency range from 100 Hz down to 50 Hz. While in the standard procedures to describe sound insulation, such as in ISO 717-1 [1], the weighting curves do not consider frequencies below 100 Hz, in the standard there is a spectral adaptation term which is used to cover the frequency range from 50 Hz up to 5000 Hz, resulting in a combined single value like $R_w + C_{50\text{-}5000}$. In order to show how the airborne sound insulation is affected by the extended frequency range down to 50 Hz, in this study, some results are presented comparing sound insulation with and without the extended frequency range. In the literature psychoacoustic measures are used to describe sound insulation features [2, 3] which will also be done in this study. A number of psychoacoustic descriptors have been used to describe sound events, including Loudness, Sharpness, Roughness and Fluctuation Strength. Various damping curves featuring airborne sound insulation have been examined.

Method of Assessment

In order to investigate the airborne sound insulation a twofold assessment was made. First it was investigated the effect using the standard procedure of ISO 717-1 [1] and ISO/NP 16717-1 [4]. The second investigation was made by using psychoacoustic descriptors. The frequency range of interest was 50 Hz up to 100 Hz. In that frequency range a dip of 6 dB was introduced and investigated.

In Figure 1 an example is shown of a frequency depending sound insulation without and with a dip of 6 dB at 100 Hz.

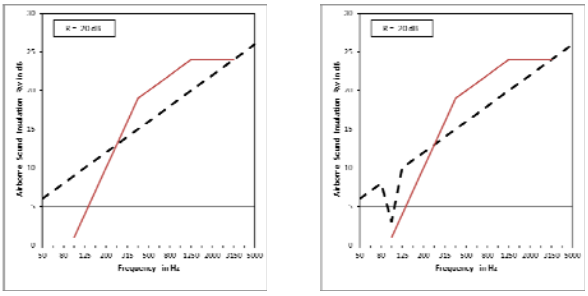

Figure 1: Airborne sound insulation without and with a dip of 6 dB at one third octave band centre frequency of 100 Hz. The solid line is the reference curve given in ISO 717-1.

The standard procedure to measure airborne sound insulation is based on the use of a broadband noise like pink or white noise. Since it is well known that many different types of sounds can be disturbing when transmitted through a partition and especially music sounds from neighbours are often said to be a main cause of annoyance and complaints [5], three music type signals were investigated in this study. The steady-state signals used in this research are therefore the two broadband noise signals, pink noise and white noise and the non-steady-state signals used are classic, rap and rock music.

The chosen classical music was Beethoven: Symphony Nr. 9: Poco Allegro, Stringendo Il Tempo, Sempre Piu Allegro – Prestissimo; the rap music was "Eminem" with the song: "*Loose Yourself*"; and the rock music was "3 Doors Down" with the song: "*Kryptonite*". All signals have a SPL of 85 dB. The power spectral density functions of the signals are shown in Figure 2.

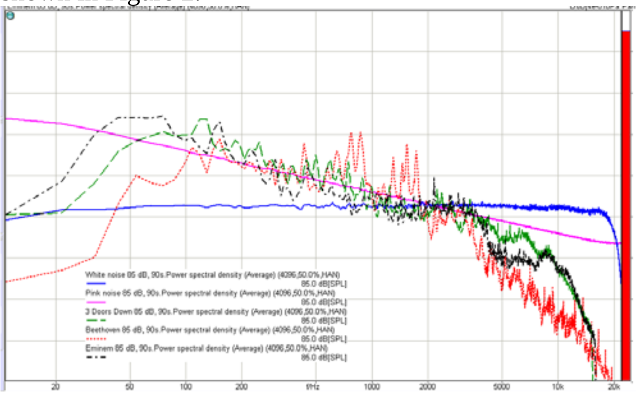

Figure 2: Power spectral density over frequency of the used signals

The source signal was filtered with a filter function (damping filter) representing the frequency depending airborne sound insulation. This filtered signal is supposed to be the receiving sound signal. Hence, it is the signal which ought to be heard by a subject. Therefore, the signal is suitable to be judged as a subjective response using psychoacoustic parameters such as Loudness, Roughness, Sharpness and Fluctuation Strength. The airborne sound insulation is described by the weighted sound reduction index (R_w) and the spectrum adaptation term (C). The weighted sound reduction index (R_w) is a single-number rating scheme intended to rate the acoustic performance of a partition element separating offices or dwellings. The higher the value of the rating is, the better the performance is. The spectrum adaptation term (C) is on the other hand a value to be added to the single-number rating and intended to correlate with subjective impressions of the sound insulation provided against sounds with different spectra. The sound spectrum is defined in ISO 717-1 [1]. The spectrum adaptation term (C) covers sources like A-weighted pink noise and is supposed to describe noise types generated by living activities such as talking, music, radio, TV, and children playing. The proposal ISO/NP 16717-1 [4] takes frequencies lower than 100 Hz into account, in particular the third octave bands 80Hz, 63Hz and 50Hz, which is supposed to make the assessment of sound insulation more complete in subjective regards. This single number rating is based on a spectral approach and proposes three kinds of reference adaptation spectra corresponding to three types of application of sound insulation in buildings. Two of them relate to noise disturbance (“traffic noise” and “living noise”) and one to privacy (“speech”). In this paper only living noise and speech are of concern and will be further investigated. The descriptors used in this study to describe airborne sound insulation are given in the Standards [see 1, 4] and are summarized in Table 1.

Table 1: Airborne sound insulation descriptors from the standards ISO 717-1 and ISO/NP 16717-1

Descriptor	Definition	Remark
R_w+C	Airborne sound insulation with reference to A-weighted pink noise and a spectrum adaptation term which has to be added in order to consider a certain sound spectra for living activities like speech, music, radio, or TV.	R_w+C = R_A if excitation is pink noise. Frequency range is 100 to 3150 Hz
R_w+$C_{50\text{-}3150}$	—	Extended frequency range to lower frequencies
R_w+$C_{100\text{-}5000}$	—	Extended frequency range to higher frequencies
R_w+$C_{50\text{-}5000}$	—	Extended frequency range 50 to 5000 Hz
R_{living}	A-weighted sound level difference from 50 to 5000 Hz with living noise excitation. This quantity corresponds to the annoyance by that type of noise.	Identical to R_w+$C_{50\text{-}5000}$. Assumes that living noise activities can be described as pink noise (A-weighted)
R_{speech}	A-weighted sound level difference from 315 to 3150 Hz with speech excitation. This quantity corresponds to the privacy of speech.	Noise from neighbouring, housing activities etc.

Results

The calculated values for a standard airborne sound insulation of R_w = 20, 40, 60 dB are depict in Table 2, where in the second row the sound insulation values are depict having no dip in the frequency curve. The bold marked values of R_w indicate the standard sound reduction index for comparison.

Table 2: Airborne sound insulation values using standard procedure of ISO 717-1 and ISO/NP 16717-1

Airborne sound insulation in dB					
Descriptor	No dip	Frequency where a dip of 6 dB occurs			
		50 Hz	63 Hz	80 Hz	100 Hz
R_w	**20/40/60**	20/40/60	20/40/60	20/40/60	20/40/60
R_w+C	19/39/59	19/39/59	19/39/60	19/39/59	19/39/59
R_w+$C_{50\text{-}3150}$	19/39/59	19/39/59	19/39/60	19/39/59	19/39/59
R_w+$C_{50\text{-}5000}$	19/39/59	19/39/59	19/39/60	19/39/59	19/38/58
R_w+$C_{100\text{-}5000}$	19/39/59	19/39/59	19/39/60	19/39/59	19/38/59
R_{living}	20/40/60	20/40/60	20/40/60	20/40/60	19/39/59
R_{speech}	18/38/58	18/38/58	18/38/58	18/38/58	18/38/58

The results shown in Table 2 are presented graphically in Figure 3.

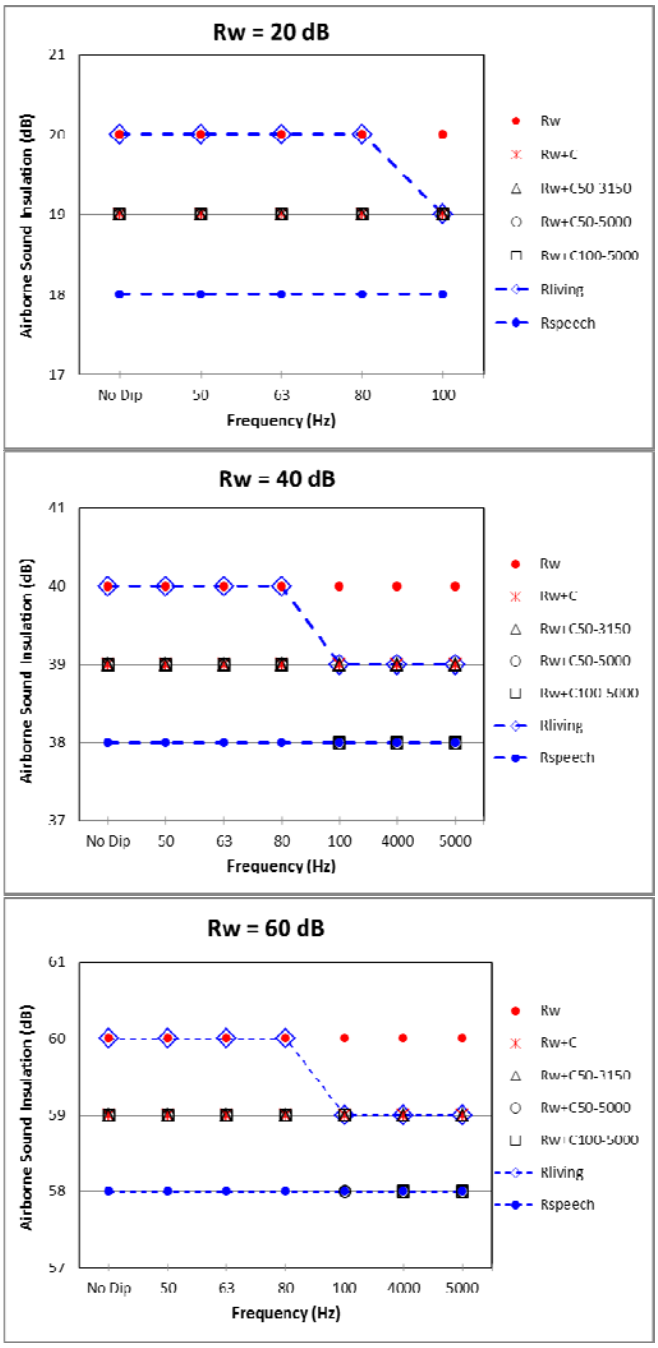

Figure 3: Airborne sound insulation without and with a dip of 6 dB in the frequency range of 50 Hz up to 100 Hz using different descriptors. The weighted sound reduction index using ISO 717-1 without the C-values is R_w = 20, 40 and 60 dB.

In order to investigate the subjective response of the signal mentioned above psychoacoustic values were calculated using the software ArtemiS of HEAD acoustics V11.

In Figure 4 the normalized specific Loudness and in Figure 5 the normalized specific Roughness, specific fluctuation Strength and Sharpness are depict for a weighted sound reduction index of R_w = 40 dB without and with a dip of 6 dB. The weighted sound reduction index, i.e. the C-value, is not used. The values (x_i) were normalized by the values calculated without a dip in the damping curve (x_0). The normalization was then done using the following equation:

$$x_N = \left(\frac{x_i}{x_0} - 1\right) * 100\% \quad (1)$$

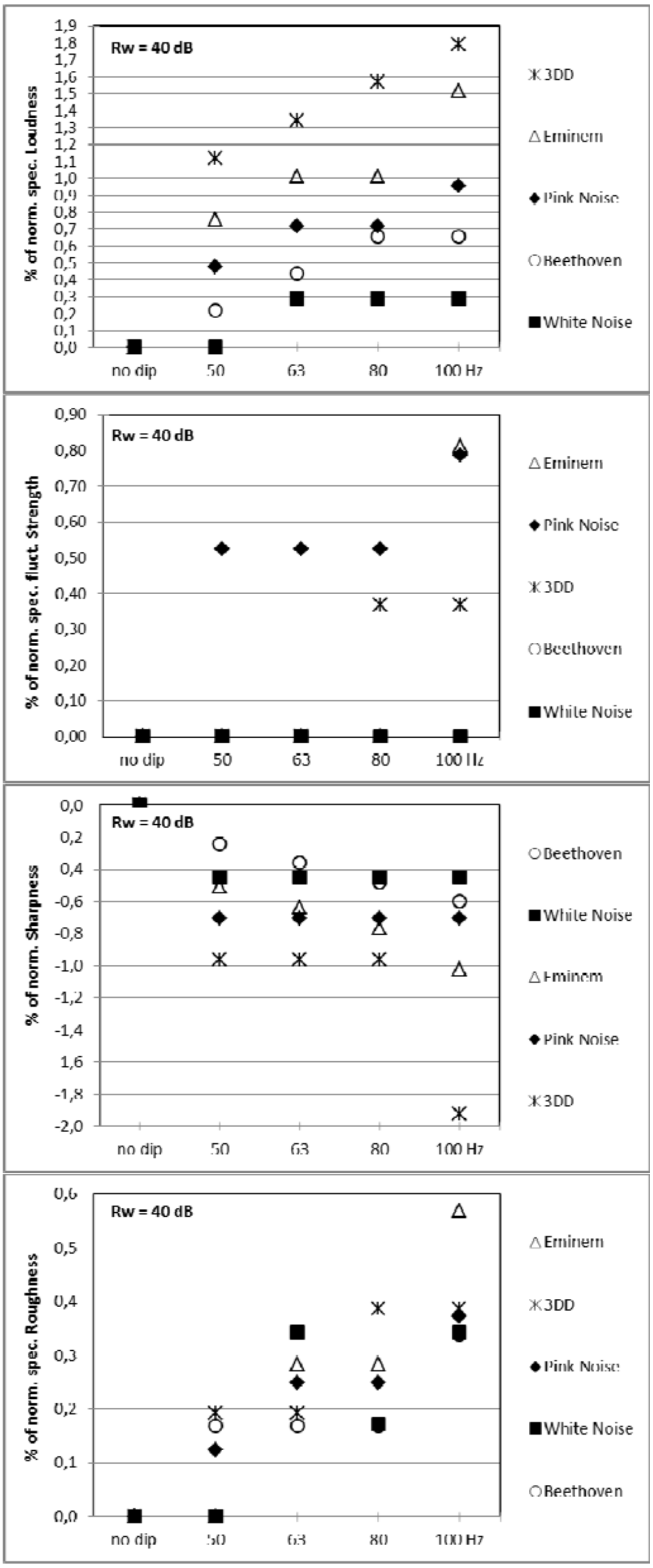

Figure 4: Normalized specific Loudness, spec. Roughness, spec. fluctuation Strength and Sharpness of an airborne sound insulation of R_w = 40 dB without and with a dip of 6 dB in the frequency range of 50 Hz up to 100 Hz using different source signals. The weighted sound reduction index is calculated using ISO 717-1 without the C-Values.

All results calculating the psychoacoustic values are shown in Table 3 to Table 6.

Table 3: Specific Loudness (N'), using a damping filter of R_w = 20, 40 and 60 dB without and with a dip at a frequency of 50, 63, 80 and 100 Hz

R_w	Pink Noise	White Noise	Beethoven	Eminem	3DD
N' (sone)					
20 dB	**17,5**	**15,0**	**18,2**	**16,6**	**18,3**
Dip at					
50 Hz	17,6	15,0	18,3	16,7	18,4
63 Hz	17,6	15,1	18,3	16,8	18,4
80 Hz	17,6	15,1	18,3	16,8	18,4
100 Hz	17,6	15,1	18,4	16,8	18,5
40 dB	**4,19**	**3,46**	**4,56**	**3,95**	**4,47**
Dip at					
50 Hz	4,21	3,46	4,57	3,98	4,52
63 Hz	4,22	3,47	4,58	3,99	4,53
80 Hz	4,22	3,47	4,59	3,99	4,54
100 Hz	4,23	3,47	4,59	4,01	4,55
60 dB	**0,308**	**0,184**	**0,585**	**0,281**	**0,412**
Dip at					
50 Hz	0,311	0,184	0,588	0,286	0,417
63 Hz	0,312	0,184	0,59	0,288	0,419
80 Hz	0,313	0,184	0,591	0,289	0,421
100 Hz	0,315	0,184	0,593	0,292	0,423

Table 4: Specific fluctuation Strength (Fls'), using a damping filter of R_w = 20, 40 and 60 dB without and with a dip at a frequency of 50, 63, 80 and 100 Hz

R_w	Pink Noise	White Noise	Beethoven	Eminem	3DD
Fls' (vacil)					
20 dB	**0,00671**	**0,00586**	**0,0640**	**0,2150**	**0,0477**
Dip at					
50 Hz	0,00671	0,00586	0,064	0,216	0,0478
63 Hz	0,00671	0,00586	0,064	0,216	0,0478
80 Hz	0,00672	0,00586	0,064	0,216	0,0478
100 Hz	0,00672	0,00587	0,064	0,216	0,0479
40 dB	**0,00381**	**0,00331**	**0,0360**	**0,1230**	**0,0271**
Dip at					
50 Hz	0,00383	0,00331	0,036	0,123	0,0271
63 Hz	0,00383	0,00331	0,036	0,123	0,0271
80 Hz	0,00383	0,00331	0,036	0,123	0,0272
100 Hz	0,00384	0,00331	0,036	0,124	0,0272
60 dB	**0,00214**	**0,00186**	**0,0202**	**0,0691**	**0,0152**
Dip at					
50 Hz	0,00215	0,00186	0,0202	0,0693	0,0153
63 Hz	0,00215	0,00186	0,0202	0,0694	0,0153
80 Hz	0,00216	0,00186	0,0202	0,0694	0,0153
100 Hz	0,00216	0,00186	0,0203	0,0695	0,0153

Table 5: Specific Roughness (R'), using a damping filter of R_w = 20, 40 and 60 dB without and with a dip at a frequency of 50, 63, 80 and 100 Hz

R_w	Pink Noise	White Noise	Beethoven	Eminem	3DD
R' (asper)					
20 dB	**2,0500**	**1,830**	**1,5800**	**1,4800**	**1,8500**
Dip at					
50 Hz	2,05	1,83	1,58	1,48	1,85
63 Hz	2,05	1,83	1,58	1,48	1,85
80 Hz	2,05	1,83	1,58	1,48	1,85
100 Hz	2,05	1,83	1,59	1,48	1,85
40 dB	**0,8050**	**0,582**	**0,5920**	**0,3520**	**0,5180**
Dip at					
50 Hz	0,806	0,582	0,593	0,352	0,519
63 Hz	0,807	0,584	0,593	0,353	0,519
80 Hz	0,807	0,583	0,593	0,353	0,520
100 Hz	0,808	0,584	0,594	0,354	0,520
60 dB	**0,0231**	—	**0,0125**	**0,0221**	**0,0454**
Dip at					
50 Hz	0,0246	—	0,0135	0,0228	0,0472
63 Hz	0,025	—	0,0138	0,0230	0,0476
80 Hz	0,0254	—	0,0141	0,0232	0,0482
100 Hz	0,0259	—	0,0145	0,0234	0,0488

Table 6: Sharpness (S), using a damping filter of R_w = 20, 40 and 60 dB without and with a dip at a frequency of 50, 63, 80 and 100 Hz

R_w	Pink Noise	White Noise	Beethoven	Eminem	3DD
S (acum)					
20 dB	**1,54**	**2,15**	**1,01**	**0,927**	**1,20**
Dip at					
50 Hz	1,54	2,15	1,01	0,923	1,2
63 Hz	1,54	2,15	1,01	0,922	1,2
80 Hz	1,53	2,15	1,01	0,920	1,2
100 Hz	1,53	2,15	1,01	0,919	1,19
40 dB	**1,42**	**2,21**	**0,831**	**0,785**	**1,04**
Dip at					
50 Hz	1,41	2,20	0,829	0,781	1,03
63 Hz	1,41	2,20	0,828	0,78	1,03
80 Hz	1,41	2,20	0,827	0,779	1,03
100 Hz	1,41	2,20	0,826	0,777	1,02
60 dB	**0,919**	**2,18**	**0,660**	**0,429**	**0,657**
Dip at					
50 Hz	0,909	2,17	0,658	0,428	0,651
63 Hz	0,907	2,17	0,657	0,429	0,650
80 Hz	0,904	2,17	0,656	0,429	0,648
100 Hz	0,901	2,17	0,655	0,429	0,645

The calculated R-values using ISO 717-1 compared with ISO/NP 16717-1 to investigate the event of a 6 dB dip at low frequencies yield results which are summarised as follows:

f < 100 Hz:
$R_w = R_{living}$
$R_w = R_{speech} + 2$ dB
$R_{speech} = R_{living} - 2$ dB
$R_w = R_w + C + 1\text{dB} = R_w + C_{50\text{-}3150} + 1\text{dB} = R_w + C_{50\text{-}5000} + 1\text{dB}$
$R_{living} = R_w + C + 1\text{dB} = R_w + C_{50\text{-}3150} + 1\text{dB} = R_w + C_{50\text{-}5000} + 1\text{dB}$

f = 100 Hz:
$R_w = R_{living} + 1$ dB
$R_w = R_{speech} + 2$ dB
$R_{speech} = R_{living} - 1$ dB

The R-value of ISO 717-1 below 100 Hz supplemented with the C-value are all identical in a certain frequency band. That means, there is no difference in the R-value if there is a 6 dB dip or not. The R-value does not reflect the event of a certain frequency dip below 100 Hz. This is also observed using the proposal of ISO/NP 16717-1. Beneath a frequency range of 100 Hz no difference is observed for R_w and R_{living}. The most change in the R-value was observed for R_{speech}, which was always -2 dB of the standard R_w-value.

However, the event of a dip in the frequency depending damping curve below 100 Hz could be observed using psychoacoustic measures. This is seen in Figure 4, for example, where the normalized values of the calculated psychoacoustic parameters in case of R_w = 40 dB are shown. The specific Loudness rises for music type signals and for pink noise. No change in Loudness is observed for white noise at frequencies of 63 and 80 Hz. No change is seen also at 50 Hz compared with no dip. For the psychoacoustic measure fluctuation strength little influence is observed concerning the effect of a dip at low frequency. The psychoacoustic measure roughness reveals changes at different dips if the sound insulation is high enough, especially for music type signals. In a previous study [6], however, it was shown, that roughness is not applicable in all cases of signal types. The results in Table 5 reveal that using white noise as a source signal provides no results in case of R_w = 60 dB. The results in sharpness show that for higher frequencies sharpness decreases. That means, lowest sharpness is observed for a dip at 100 Hz. White noise does not changes sharpness in all cases even if there is no dip in the damping curve (see Table 6).

Conclusions

In this study it is shown that the proposed new descriptor in ISO/NP 16717-1 does not improve the subjective impression if there is a significant dip of 6 dB in the damping curve occurring at low frequency below 100 Hz. On the other hand, this study shows that psychoacoustic values may help to improve the description of airborne sound insulation, more related to subjective impression.

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