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Noise
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4pNSb1. Airborne sound insulation as a measure for noise annoyance

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There is currently a lack of measure to describe airborne sound insulation in terms of subjective evaluation of noise annoyance. With a given sound insulation value, different kinds of sound signals could produce rather different hearing sensation levels. Physical noise measurements to describe airborne sound insulation often cannot solve problems in terms of noise annoyance, and psychoacoustic metrics are increasingly used. Recently, new results of evaluating sound insulation spectra by single-numbers have been adapted for practical applications such as in ISO 16717-1. In this paper comparisons are carried out to demonstrate how single-number ratings are affected by non-steady-state sounds. The effect of a sound insulation having a frequency dip of 6 dB has also been examined. It is well known that noises with tonal components could be rather annoying, so that it would be of significance to examine if a frequency depending sound insulation can act as a filter for tonal components. In this paper it will be shown that psychoacoustic magnitudes like loudness, sharpness and fluctuation strength can largely account for different aspects, especially if airborne sound insulation is supposed to describe hearing sensation.

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INTRODUCTION

In the literature [1-7] it is frequently discussed that single number ratings based on standard procedures like ISO 717 [8] leads to different results concerning subjectively related judgments. As in [6] stated: "*The compilation of data on R_w and $C_{50\text{-}3150}$ of all types of building elements on the one hand and studies on the subjective response on sound insulation on the other hand show that the consideration of the low frequencies down to 50 Hz is very important*." A single number rating which is correlated with a subjective rating should be closely related to psychoacoustic measures. In this paper comparisons are carried out to demonstrate how a given sound insulation value produces different hearing sensation levels if different sound signals are used. The effect of a sound insulation with a frequency dip of 6 dB has also been examined. In order to compare psychoacoustic measures elementary auditory sensations [9] including loudness, sharpness and roughness have been chosen. Additionally, fluctuation strength has been examined in this study as another important hearing sensation. Psychoacoustic values were calculated using the software ArtemiS of HEAD Acoustics V11. The aim is to show that psychoacoustic magnitudes can largely account for different aspects, especially if airborne sound insulation is supposed to describe hearing sensation.

RATING METHODS

In this study the rating is twofold. First the rating of the Standard ISO 717-1 [1] and the new proposal ISO/NP 16717-1 [10] are compared. Second, a sound signal is investigated using psychoacoustic measures. Since a sound insulation of a partition can be regarded as a filter to an unprocessed sound signal, the processed signal is then supposed to be the signal which contains all information which is subjectively regarded to be the true value of an airborne sound insulation. This filter, i.e. the coefficients of the built transfer function, are generalised damping coefficients in the frequency range of 50 to 5000 Hz, characterising the frequency dependent R-values [11]. The investigation in this study was in a way, that at each one-third octave band centre frequency a dip of 6 dB was introduced, keeping the R-value constant. The signal which is filtered with the filter function is regarded as the transmitted sound signal. This sound signal is used for the rating procedure using psychoacoustic measures.

Signal Description

The random signal pink noise which is also known as 1/f-noise is a signal with a frequency spectrum such that the power spectral density is proportional to the reciprocal of the frequency. There is equal energy in all octave bands. In terms of power at a constant bandwidth, 1/*f*-noise falls off at 3 dB per octave. Pink noise is usually used to measure the sound insulation.

To investigate how the single-number ratings of the standard procedure of ISO 717-1 and a new proposal ISO/NP 16717-1 are affected by non-steady-state sounds, two music type signals were investigated in this study, namely classic and rap 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*". All signals used in this research had duration of 90 s and an overall sound pressure level (SPL) of 85 dB. This type of music was also investigated in [11, 12]. The time signal for the sound signal Beethoven and Eminem is illustrated in Figure 1.

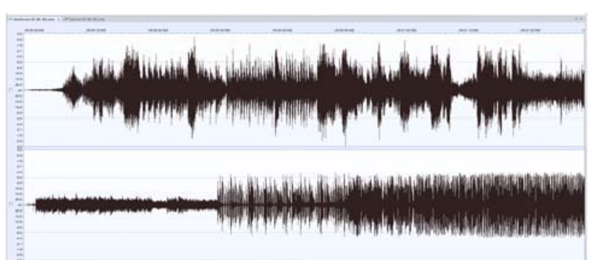

FIGURE 1. Time signal of Beethoven and Eminem with SPL of 85 dB and duration 90 s.

The power spectral density (PSD) over frequency of the used signals is shown in Figure 2.

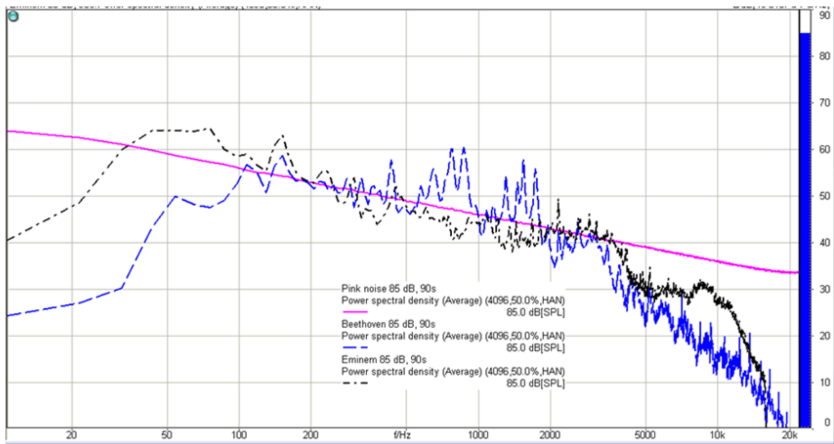

FIGURE 2. Power spectral density of the used signals, including pink noise, Beethoven and Eminem, having a SPL of 85 dB.

In order to investigate the event of a frequency dip in the damping function the power spectral density of the signal is calculated using pink noise as a signal. The power spectral density of the airborne sound insulation with different levels of sound reduction index (R_w) is shown in Figure 3. The parameter "R_w = 0 dB" relates to the unfiltered signal. The parameters R_w = 20, 40, 60 dB relates to the filter functions with which the sound signal was processed.

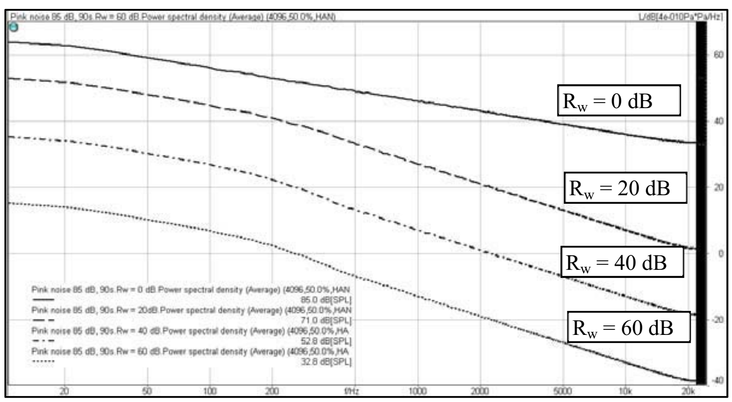

FIGURE 3. Power spectral density of the sound signals, with pink noise unfiltered and filtered with a damping function related to a damping of R_w = 20, 40, and 60 dB. R_w = 0 dB indicates unprocessed sound signal.

The calculated psychoacoustic values of the used signals are shown in Table 1.

TABLE 1. Psychoacoustic values of the signals, including pink noise, Beethoven and Eminem, as shown in Figure 2

Sound Signal	**Spec. Loudness N'** (sone)	**Spec. Roughness R'** (asper)	**Spec. Fluctuation Strength Fls'** (vacil)	**Sharpness S** (acum)
Pink noise	60.0	3.95	0.0107	2.15
Beethoven	58.3	3.14	0.106	1.39
Eminem	54.4	3.27	0.356	1.32

Filter Function

As mentioned above, the sound insulation of a partition is regarded to be a filter to a sound signal which is transmitted through this partition. This filter, i.e. the coefficients of the built transfer function, are generalised damping coefficients in the frequency range 50 to 5000 Hz characterising the frequency dependent R-values [11]. The airborne sound insulation is described by the weighted sound reduction index (R_w) and the spectrum adaptation term (C). The spectrum adaptation term (C) is a value to be added to the single-number rating and is 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. 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. In this study only living noise and speech are of concern and will be further investigated. The R-values investigated are 20, 40, and 60 dB. In Figure 4 is an example is shown on the frequency dependent sound insulation of 40 dB with and without a dip of 6 dB at a frequency of 100 Hz and of 500 Hz, respectively.

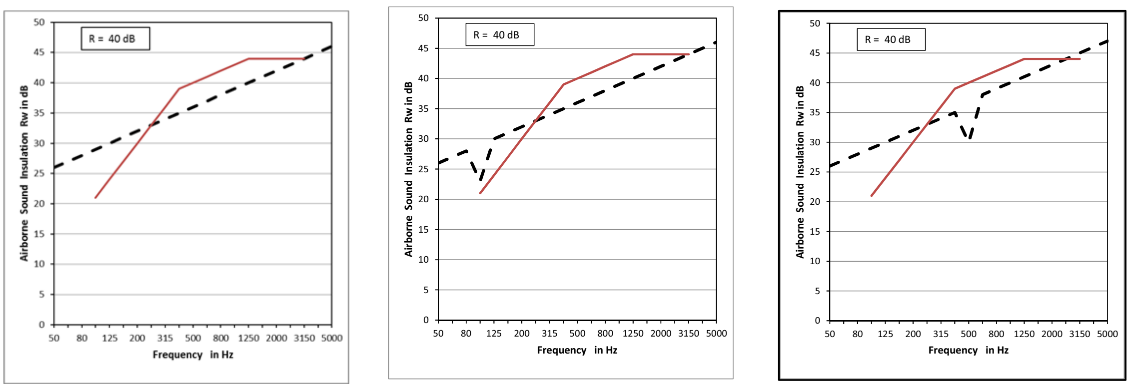

FIGURE 4. Airborne sound insulation without (left) and with a dip of 6 dB at 1/3 octave band centre frequency of 100 Hz (middle) and of 500 Hz (right). The solid line is the reference curve given in ISO 717-1.

The power spectral density function for the unprocessed signal pink noise and the filtered signal including the introduced dip at frequencies from 50 up to 5000 Hz are depict in Figure 5. From the plot it is seen that at frequencies above 315 Hz a dip in the power spectral density function occurs. Between 400 Hz and 100 Hz a dip of 6 dB is gradually vanishing and visually hardly recognizable. Below 100 Hz the dip is not visually recognizable and no numerical differences are observed. This is in agreement with [13].

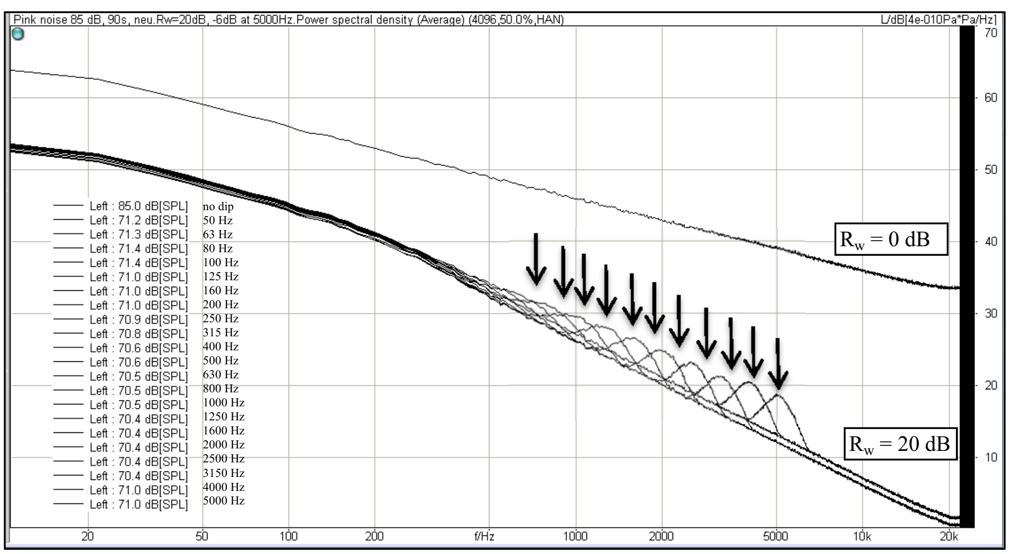

FIGURE 5. Power spectral density of the sound signal pink noise filtered with an R-value of 20 dB with a dip of 6 dB at each 1/3 octave band centre frequency form 50 Hz up to 5000 Hz. The sound pressure level of the unprocessed sound signal is 85 dB.

RATINGS: ISO 717-1 VERSUS ISO/NP 16717-1

The calculated values for an 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 the sound reduction index R_w indicate the standard value which is marked 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											
		Frequency (Hz) where a dip of 6 dB occurs									
Descriptor	**No dip**	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**
R_w	**20/40/60**	20/40/60	20/40/60	20/40/60	20/40/60	20/40/60	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	19/39/59	19/39/59	19/40/60	19/39/59	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	19/39/59	19/39/59	19/39/59	19/39/59	19/39/59	18/38/58
R_w+$C_{50\text{-}5000}$	19/39/59	19/39/59	19/39/60	19/39/59	19/38/58	18/38/58	18/38/59	18/39/59	18/38/59	19/39/59	18/38/58
R_w+$C_{100\text{-}5000}$	19/39/59	19/39/59	19/39/60	19/39/59	19/38/59	18/38/58	18/38/59	18/38/59	18/38/59	19/39/59	17/37/57
R_{living}	20/40/60	20/40/60	20/40/60	20/40/60	19/39/59	19/39/59	19/39/60	19/38/60	19/39/60	19/39/59	19/39/59
R_{speech}	18/38/58	18/38/58	18/38/60	18/38/58	18/38/58	18/38/58	19/39/59	19/39/59	19/39/59	19/39/59	17/37/57
Descriptor	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**
R_w	20/40/60	20/40/60	20/40/60	20/40/60	20/40/60	20/40/60	20/40/60	20/40/60	20/40/60	20/40/60	20/40/60
R_w+C	18/38/58	18/38/58	18/38/58	18/38/58	18/38/58	18/38/58	19/39/59	19/39/59	19/39/59	19/39/59	19/39/59
R_w+$C_{50\text{-}3150}$	18/38/58	18/38/58	18/38/58	18/38/58	18/38/58	18/38/58	19/39/59	19/39/59	19/39/59	19/39/59	19/39/59
R_w+$C_{50\text{-}5000}$	17/37/57	17/37/57	17/37/57	17/37/57	17/37/57	17/37/57	18/38/58	18/39/58	18/39/59	18/38/58	18/38/58
R_w+$C_{100\text{-}5000}$	17/37/57	17/37/57	17/37/57	17/37/57	17/37/57	17/37/57	18/38/58	19/39/59	18/39/59	18/38/58	18/38/58
R_{living}	19/39/59	19/39/59	19/39/59	19/39/59	19/39/59	19/39/59	19/39/59	19/39/59	20/39/60	19/39/59	19/39/59
R_{speech}	17/37/57	17/37/57	17/37/57	18/38/58	18/38/58	18/38/58	18/38/58	18/38/58	19/38/58	18/38/58	18/38/58

It is seen in Table 2 that for example R_w = 20 dB without a dip in the damping curve yields R_{speech} = 18 dB. The damping curve with a dip at a frequency of 500 Hz yields R_w = 20 dB and R_{speech} = 17 dB. That is, a dip reduces the R_{speech} value by 1 dB whereas R_w is not affected by this dip. Note, below 100 Hz R_{speech} and R_{living} are not affected by a dip of 6 dB in the frequency range.

It is noted that the difference between the various ratings is about 3 dB in maximum. The values using the standard ISO 717-1 without a spectrum adaptation term always yields highest ratings followed by the newly proposed descriptor R_{living} of ISO/NP 16717-1. In Figure 6 the numerical values for the cases R_w = 40 dB and R_w = 60 dB are presented graphically.

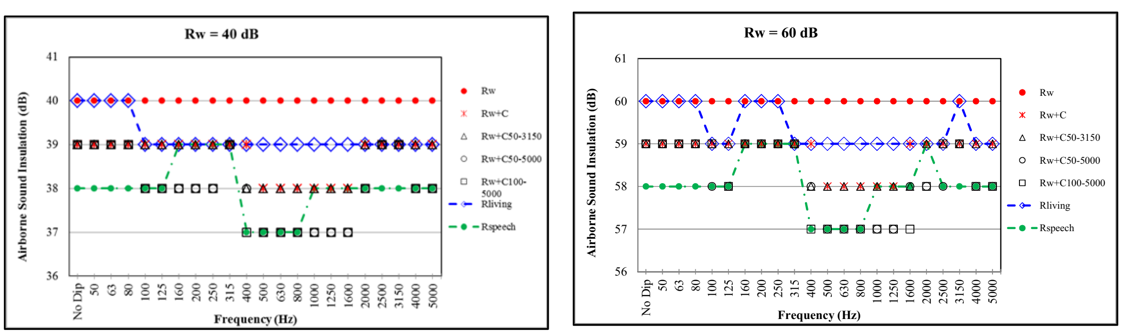

FIGURE 6. Airborne sound insulation with and without a dip of 6 dB in the frequency range of 50 to 5000 Hz using different descriptors. The weighted sound reduction index using ISO 717-1 without the C-values is R_w = 40 and 60 dB.

PSYCHOACOUSTIC RATINGS

In order to describe a sound event psychoacoustic measures are commonly used. Loudness as a measure for the hearing sensation is well-known, referring to the human perception of sound volume. Sharpness is a hearing sensation related to frequency and independent of loudness, and is supposed to be a measure which can be considered separately and hence can be used to compare different sounds. Since Sharpness is most influenced by the spectral content it is investigated in this study for comparison. Another psychoacoustic measure used to determine the subjective judgment of sound quality is Roughness. As stated in [9] Roughness is a sensation which can be considered while ignoring other sensations. Close to that measure is the hearing sensation Fluctuation Strength, which is related to loudness modulations at low frequencies that are noticeable individually. Fluctuation Strength is investigated due to the fact that this measure is related to speech since the maximum Fluctuation Strength for a modulation frequency of about 4 Hz seconds its counterpart in the variation of the temporal envelope of fluent speech [9]. It is therefore interesting to see how these psychoacoustic measures do reflect an event of a frequency dip in the damping curve. Similar investigations were made in the literature [14], although in a smaller frequency range. In order to show the effect of a frequency dip, in Figure 7 the Specific Loudness of the signal pink noise for a damping value of 40 dB with a dip in each 1/3 octave band frequency is depict. For comparison, in Figure 8 the Specific Loudness of the signal Beethoven is shown. Note in Figures 7 to 10 the frequency is given in Bark so that for example 2 Bark corresponds to a centre frequency of about 150 Hz, 6 Bark corresponds to 570 Hz, 9 Bark to 1 kHz and 12 Bark to 1.6 kHz, 15 Bark to 2.5 kHz and 18 Bark corresponds to about 4 kHz.

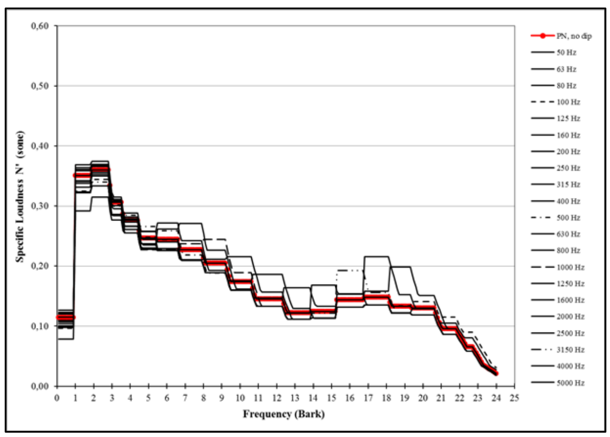

FIGURE 7. Specific Loudness of the filtered sound signal pink noise. The airborne sound insulation is R_w = 40 dB with and without a dip of 6 dB in the frequency range of 50 to 5000 Hz. The red solid line indicates no dip in the filter function.

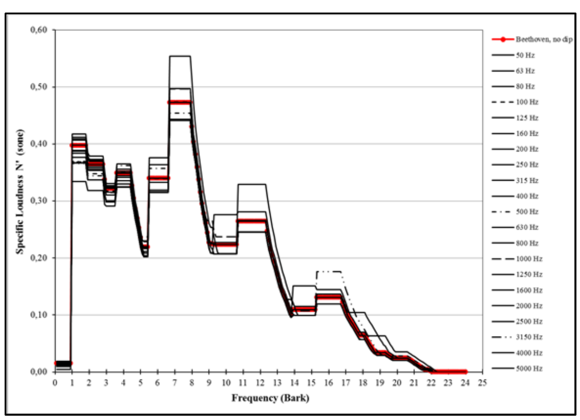

FIGURE 8. Specific Loudness of the filtered sound signal Beethoven. The airborne sound insulation is R_w = 40 dB with and without a dip of 6 dB in the frequency range of 50 to 5000 Hz. The red solid line indicates no dip in the filter function.

Through comparison it is seen that the steady-state sound signal pink noise as well as the non-steady-state sound sample Beethoven reflect the event of a dip in the frequency dependent airborne sound insulation in the Loudness function. This effect is also seen in the Figures 9 and 10 where the Specific Fluctuation Strength is depict. Loudness level calculated for pink noise spectra and for music spectra shown in Figure 7 and 8 indicate that the effect of low frequency content is more influencing on non-steady-state sounds. For steady-state sounds like pink noise it is concluded that a dip at mid and high frequencies contributes more to Loudness than a dip at low frequencies.

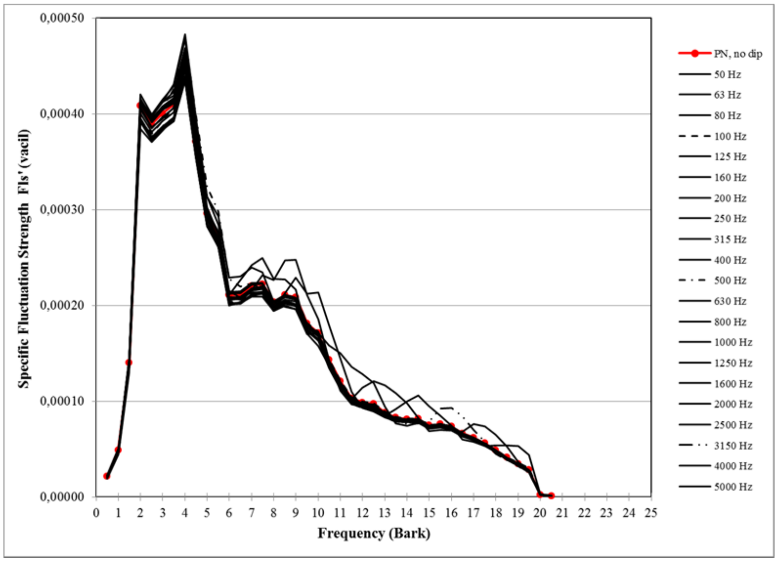

Figure 9. Specific Fluctuation Strength of the filtered sound signal pink noise. The airborne sound insulation is R_w = 40 dB with and without a dip of 6 dB in the frequency range of 50 to 5000 Hz. The red solid line indicates no dip in the filter function.

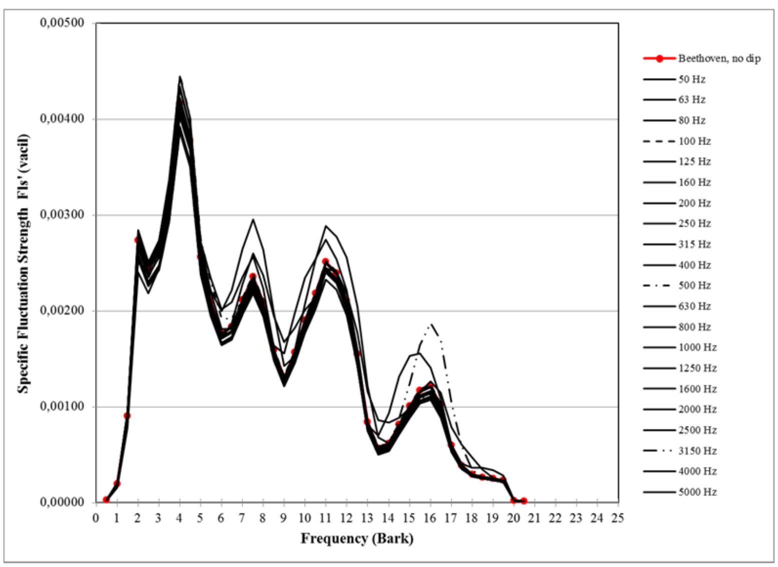

Figure 10. Specific Fluctuation Strength of the filtered sound signal Beethoven. The airborne sound insulation is R_w = 40 dB with and without a dip of 6 dB in the frequency range of 50 to 5000 Hz. The red solid line indicates no dip in the filter function.

It is observed in the figures above that the event of a dip in the frequency range between 50 to 5000 Hz is evident especially at mid and high frequencies. In Figure 11 Sharpness, Loudness, Specific Fluctuation Strength, and Specific Roughness are depict for the example of an airborne sound insulation of 40 dB.

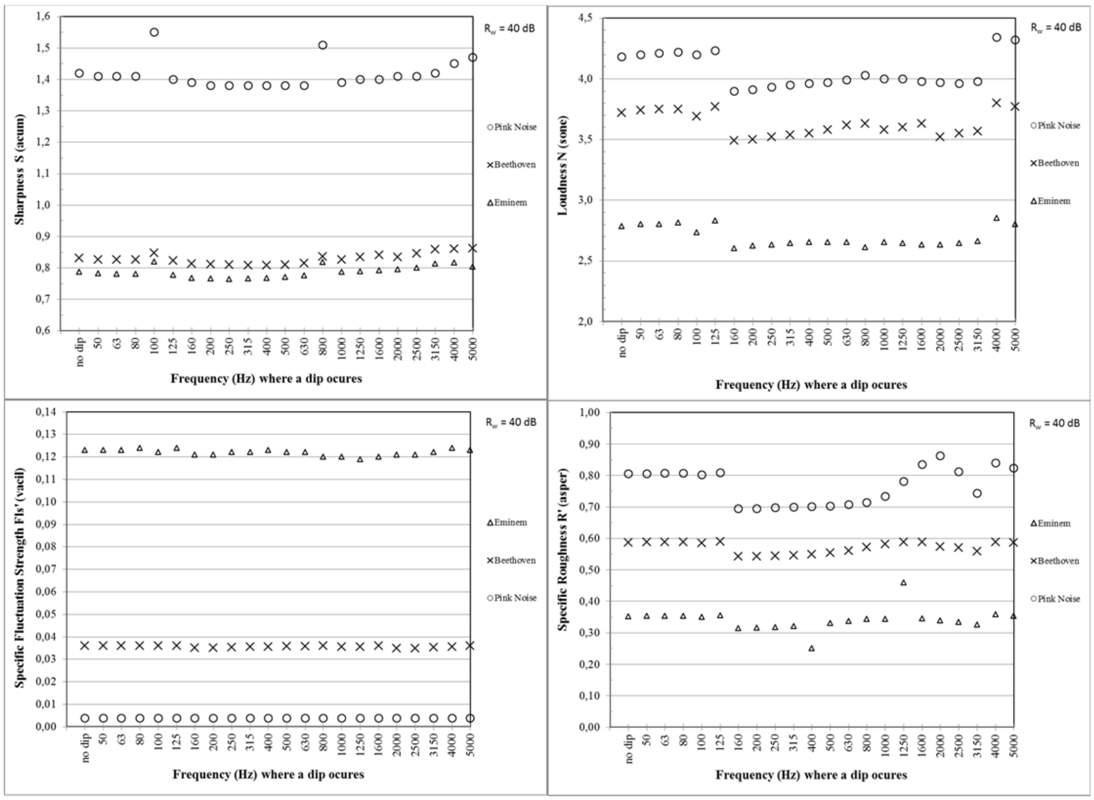

Figure 11. Sharpness, Loudness, Specific Fluctuation Strength, and Specific Roughness of the filtered sound signals pink noise, Beethoven, and Eminem. The airborne sound insulation is R_w = 40 dB with and without a dip of 6 dB in the frequency range of 50 to 5000 Hz.

CONCLUSIONS

In Table 2 the different rating descriptors of ISO 717-1 and ISO/NP 16717-1 are presented, showing that differences between the various ratings is about 3 dB in maximum. The values using the standard ISO 717-1 without a spectrum adaptation term yields always highest ratings followed by the new proposed descriptor R_{living} of ISO/NP 16717-1. 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 (f < 100 Hz) yield results which are summarised as follows:

$R_w = R_{living}$

$R_w = R_{speech}$ + 2 dB

$R_{speech} = R_{living}$ - 2 dB

$R_w = (R_w+C)$+1dB = $(R_w+C_{50\text{-}3150})$+1dB = $(R_w+C_{50\text{-}5000})$+1dB

$R_{living} = (R_w+C)$+1dB = $(R_w+C_{50\text{-}3150})$+1dB = $(R_w+C_{50\text{-}5000)}$+1dB

The psychoacoustic values reveal that there is a significant difference using a steady-state or a non-steady-state sounds signal. In case of an identical filter function the resulting psychoacoustic measures were quite different. That means that the subjective impression of the transmitted sound signal is different even if the single number rating is identical. This corresponds to results reported in [11].

Overall, in this study it is shown that at low frequency below 100 Hz 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. From comparison the study showed that a frequency dip in the airborne sound insulation can be pictured using psychoacoustic measures. The investigation also showed that there is a strong influence to some of the psychoacoustic measure in the low frequency rang as well as in the high frequency range. It is noted that the psychoacoustic measures are most influenced by a frequency dip at mid and high frequencies. As a result, psychoacoustic measures may help to improve the description of airborne sound insulation, more related to subjective impression. However, it turned out that there is no consistency in both the single number rating scheme as well as in the psychoacoustic ratings.

It is expected that the investigation presented here may inspire research for assessing limitations and potential improvements of subjective related airborne sound insulation rating methods based on a single number rating scheme and psychoacoustic measures.

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