Time Structure Of The Signal In Airborne Sound Insulation

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Summary
The airborne sound insulation of building elements like walls and floors dividing different spaces in a multi-family house is not only intended to avoid speech transmission in terms of a certain intelligibility score, but also to prevent people from unacceptable noise level considering noise annoyance and also possible health problems. Usually, airborne sound insulation quality of a construction is given by a single number rating. In Europe, this rating is performed using the Standard EN 717-1, taking into account the measured frequency dependent values of the airborne sound insulation. This procedure is problematic due to the fact that the time dependent information is omitted. In the preliminary investigation presented in this paper, time dependent features of signals have been examined in relation to the subjectively judged airborne sound insulation in terms of psychoacoustic parameters. It has been shown that the time dependent information of the transmitted signal through a partition is a very sensitive and important part for airborne sound insulation, but it is not considered in current regulations and standards.

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1. Introduction

Airborne sound insulation has been studied for a long time [1] [2] [3]. In Europe there is a generally accepted Standard EN 12354-1 [4] to calculate the sound insulation. Comparison of predicted and measured airborne sound insulation using the Standard EN ISO 717-1 [5] may lead the same numerical values in sound insulation. However, comparing single number quantities of airborne sound insulation with subjective estimated airborne sound insulation yield frequently serious differences. Both, EN 12354-1 for the prediction as well as EN ISO 717-1 for the calculation are problematic due to the fact that the time dependent information is omitted [6]. In the preliminary investigation presented in this paper, time dependent features of signals are examined in relation to airborne sound insulation. It will be shown, that the time dependent information of the transmitted signal through a partition is a very sensitive and important part for airborne sound insulation.

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2. Frequency dependence

The measured frequency depending airborne sound insulation is converted in a single number rating using the Standard ISO 717-1 [5]. In general this procedure uses a reference curve shifted against the measured values. Figure 1 shows an idealised frequency dependent airborne sound insulation and the reference curve according to ISO 717-1.

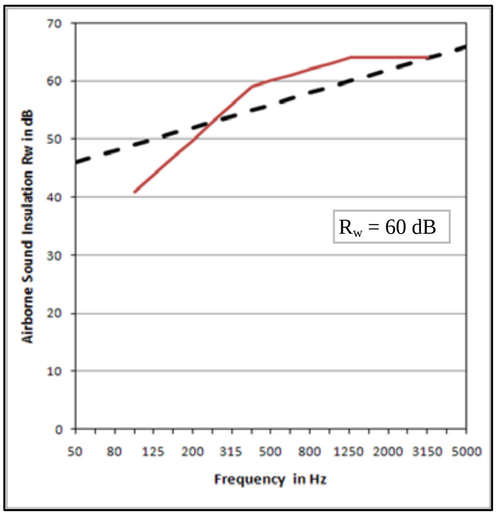

Figure 1. Idealised airborne sound insulation as a function of frequency. The solid line is the reference curve given in EN ISO 717-1. Example R_w = 60 dB.

3. Time dependence

3.1 Sound Source Signals

This study uses two different types of signals, steady-state signals and non-steady-state signals. The steady-state signals are two broadband noise signals, namely pink noise and white noise. The non-steady-state signals are two music samples, namely classic and rap music. The chosen classical music was Beethoven: Symphony Nr. 9: Poco Allegro, Stringendo Il Tempo, Sempre Piu Allegro - Prestissimo, and the rap music was: “Eminem” with the song: “Loose Yourself“. All signals have a SPL of 85 dB.

3.2 Sound Pressure Level

Airborne sound insulation is usually measured in terms of a sound pressure level (SPL) difference. This considers the sound in the receiving room after being transmitted through a partition. The measured time dependent airborne sound insulation as a function of time transformed in a single number quantity may be expressed in terms of a SPL. This SPL is the transmitted sound in the receiving room which will occur at the listener’s ear and is therefore supposed to be the most important parameter in representing the quality of the sound insulation. This SPL contains all important information in order to judge the sound insulation in terms of sensation. Figure 2 shows the SPL of various source signals of 85 dB after passing the filter of 60 dB as shown in Figure 1.

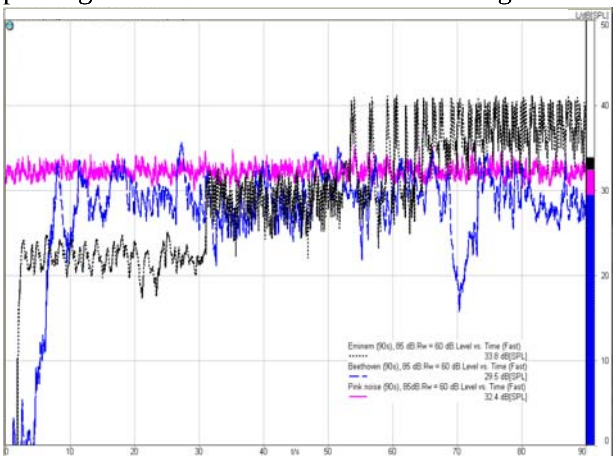

Figure 2. Time spectrum of pink noise and two music samples as source signal after transmission through a “filter” of 60 dB (see Figure 1) yielding different SPL.

The resulting SPL after transmission is illustrated in Figure 3. It is seen that if different source signals are applied the resulting SPL after transmission is not the same. This means that the sound insulation is not constant but depends on the source signal and its spectral content.

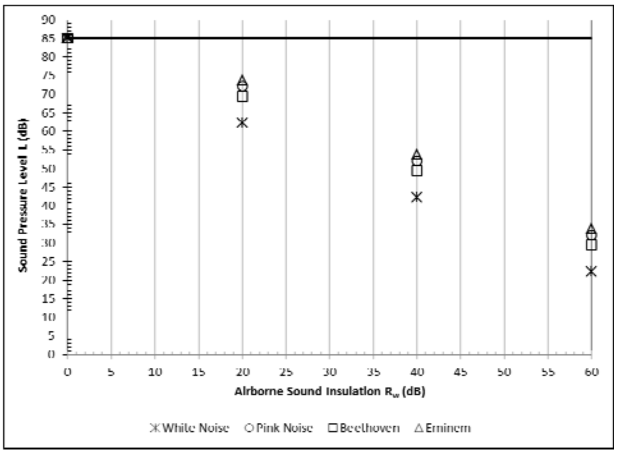

Figure 3. Calculated SPL after transmission. All source signals have a SPL of 85 dB.

3.3 Loudness

Calculating loudness of different transmitted sound signals for judging the sound reveals that although all source signals have the same SPL of 85 dB, different loudness values are obtained.

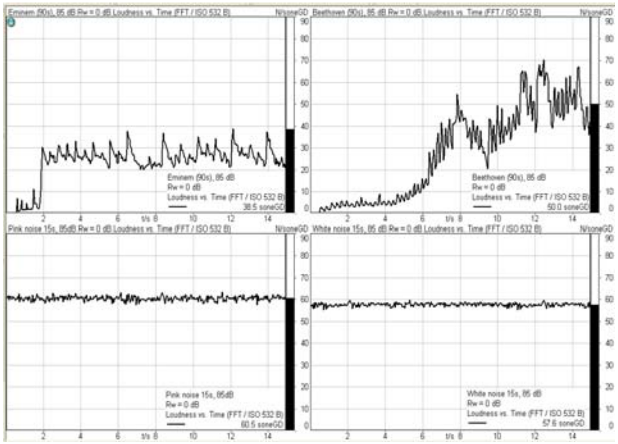

Figure 4. Loudness vs Time of the source signals, including two music samples, i.e. Eminem (Rap) and Beethoven (Classic) and two noise type samples, i.e. pink noise and white noise. All source signals have a SPL of 85 dB.

It is seen that pink noise has a loudness of 60.5 sone, white noise 57.6 sone, Beethoven 50.0 sone and Eminem 38.5 sone. With increasing sound insulation it is concluded, that loudness decreases, as expected. In Figure 5 the calculated loudness is shown as a function of airborne sound insulation.

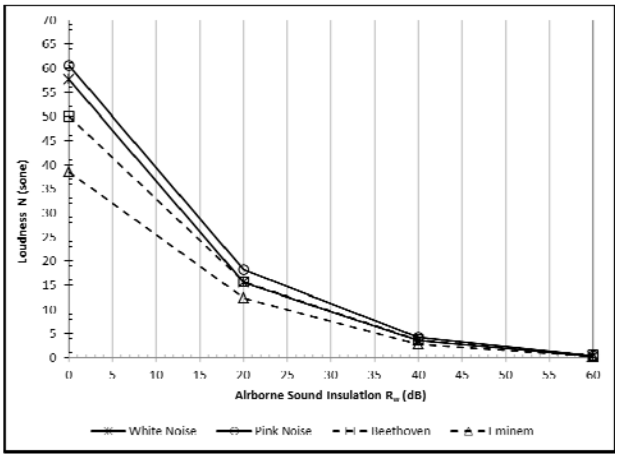

Figure 5. Loudness of source signals after transmission. All source signals have a SPL of 85 dB.

As can be seen in Figure 5, there is a variation in resulting loudness of the received SPL after transmission. Loudness varies with different source signals. This confirms the assumption that sound insulation depends on the type of source signal and its spectral content.

3.4 Sharpness

Sound signals whose spectral components are mainly at higher frequencies located are judged subjectively as "sharp". The variability of sharpness judgments is comparable to that of loudness judgments [7]. One of the most important parameter influencing sharpness is the spectral content of a signal. In Figure 6 the calculated sharpness is shown as a function of time.

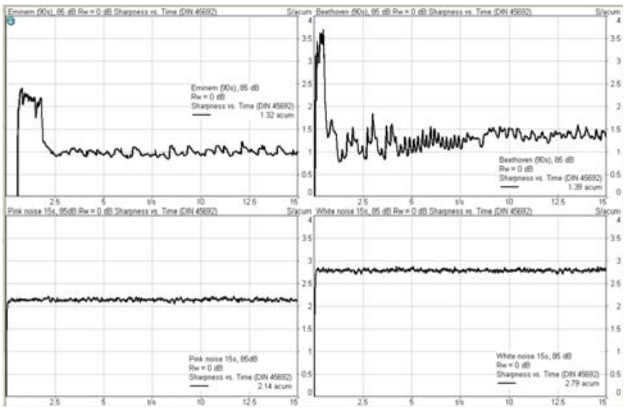

Figure 6. Sharpness vs Time of source signals, including two music samples, i.e. Eminem (Rap) and Beethoven (Classic) and two noise type samples, i.e. pink noise and white noise. All source signals have a SPL of 85 dB.

Sharpness of “Eminem” is 1.32 acum and of “Beethoven” 1.39 acum. Sharpness of pink and white noise was calculated to be 2.14 acum and 2.79 acum, respectively. Sharpness is very similar for the two groups of source type signals.

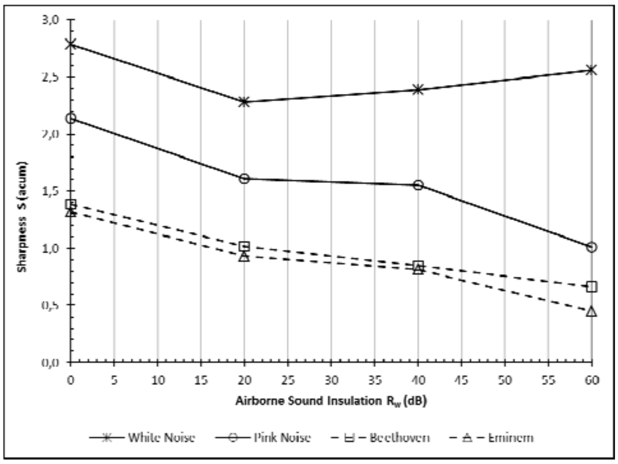

Figure 7. Sharpness after transmission. All source signals have SPL of 85 dB.

Figure 7 reveals that the noise type source signal has higher sharpness than music type source signals. Moreover, the used noise type signals, i.e. white and pink noise, spread much more apart than the investigated two music type signals. The white noise signal reveals additionally some unexpected behaviour with increasing insulation. While all other source signals decreases in sharpness with increasing sound insulation, white noise does not.

3.5 Roughness

The psychoacoustic magnitude roughness describes temporal variations of sounds and it is created by the relatively quick changes produced by modulation frequencies in the region between about 15 to 300 Hz [7]. Roughness is calculated for the two music type samples. In Figure 8 results are shown.

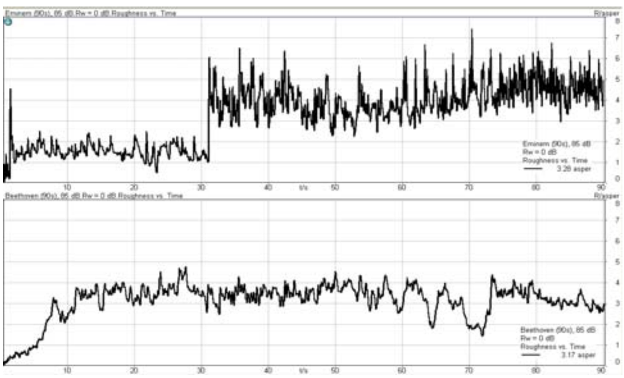

Figure 8. Roughness vs Time of source signals, considering two music samples, i.e. Eminem (Rap) and Beethoven (Classic). All source signals have a SPL of 85 dB.

From comparison it is seen that “Eminem” has 3.28 asper and “Beethoven” has 3.17 asper, i.e. both music types have similar roughness.

3.6 Tonality

Tonality is another psychoacoustic measure to describe a signal and its temporal characteristics. Tonality is a measure of the proportion of tonal components in the spectrum of a signal and allows a distinction between tones and noises. Broadband noises like white and pink noise have no or little tonality. Tonality is calculated for the two music type samples, as shown in Figure 9.

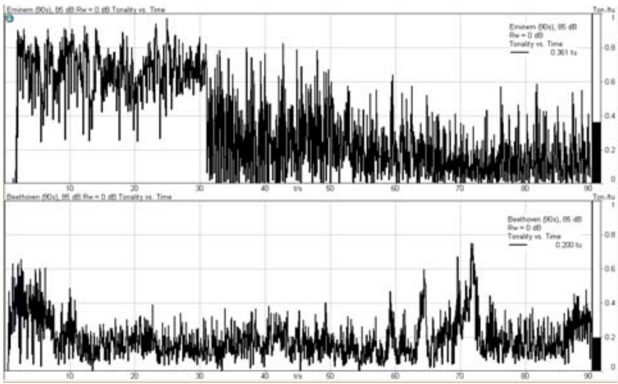

Figure 9. Tonality vs Time of source signals, considering two music samples, i.e. Eminem (Rap) and Beethoven (Classic). All source signals have a SPL of 85 dB.

It is seen that the source signal “Beethoven” has tonality of 0.20 tu and “Eminem” of 0.361 tu. In the first 30 seconds the music type sample “Eminem” contains higher tonality, and beyond 58 ms “Beethoven” shows some clear peak values. Overall “Eminem” is however, more “peakyness” than “Beethoven”.

4. Comparison of Psychoacoustic Factors

The psychoacoustic factors of the investigated sound source signals are given in Table I. These psychoacoustic measures characterise the signals before transmission through a filter.

Table I. Psychoacoustic factors of the source signal: SPL (SPL), Loudness (N), Sharpness (S), Rougness (R) and Tonality (Ton).

Sound sample	*SPL [dB]*	*N [sone]*	*S [acum]*	*R [asper]*	*Ton [tu]*
White Noise	85	57.6	2.79	3.61	0.019
Pink Noise	85	60.5	2.14	3.96	0.018
Beethoven	85	50.0	1.39	3.17	0,200
Eminem	85	38.5	1.32	3.28	0,361

In Table II the psychoacoustic measures are shown after transmission. The applied filter function is 60 dB, as shown in Figure 1.

Table II. Psychoacoustic factors of the signal after transmission: SPL (SPL), Loudness (N), Sharpness (S), Roughness (R) and Tonality (Ton).

Sound sample	*SPL [dB]*	*N [sone]*	*S [acum]*	*R [asper]*	*Ton [tu]*
White Noise	22.3	0.205	2.56	0.0	0.0
Pink Noise	32.1	0.323	1.01	0.0188	0.017
Beethoven	29.5	0.452	0.67	0.0105	0,249
Eminem	33.8	0.238	0.45	0.0204	0,318

By comparing the two tables it is seen that white noise yield a zero value for roughness and tonality for high sound insulation. This result leads to the conclusion, that roughness and tonality are not suitable predictors for a rating procedure concerning sound insulation.

5. Specific Fluctuation Strength

In contrast to the psychoacoustic measure roughness, which has an envelope fluctuation between 20 Hz and 300 Hz, the specific fluctuation strength has modulation frequencies under 20 Hz. Fluctuation strength reaches a maximum for modulation frequencies around 4 Hz and plays a vital role in the assessment of human speech [9]. This will be detected by a listener as time modifications and hence results in a perception of fluctuation strength. In general this measure is a psychoacoustic analysis of the human perception of a slowly varying modulation of the signal based on the hearing model [7]. In Table III the specific fluctuation strength is shown for different airborne sound insulation values and the results are also presented graphically in Figure 10.

Table III. Spec. Fluctuation Strength for different sound samples and varying sound insulation.

Specific Fluctuation Strength, spec. Fls in vacil				
	Airborne Sound Insulation R_w in dB			
	0	20	40	60
White Noise	0.0166	0.0120	0.0068	0.0038
Pink Noise	0.0223	0.0146	0.0082	0.0046
Beethoven	0.1060	0.0640	0.0360	0.0202
Eminem	0.3560	0.2170	0.1220	0.0688

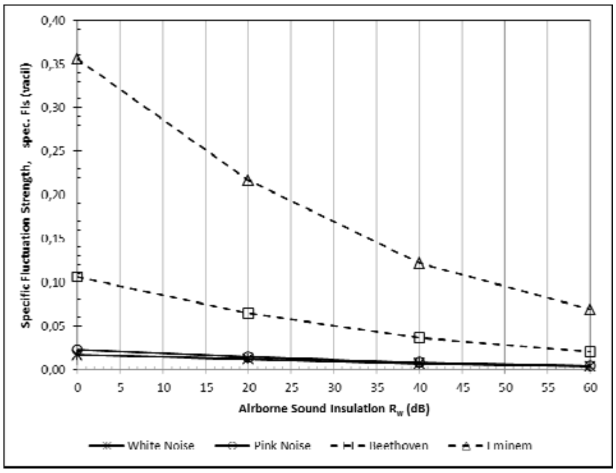

Figure 10. Specific fluctuation strength as a function of airborne sound insulation for different source signals. All source signals have SPL of 85 dB.

Based on Figure 10 it is seen, that noise has just little or almost no fluctuation. This is expected. However, music type signals are highly fluctuating. The difference in specific fluctuation strength caused by a change in airborne sound insulation in steps of 20 dB is shown in Figure 11.

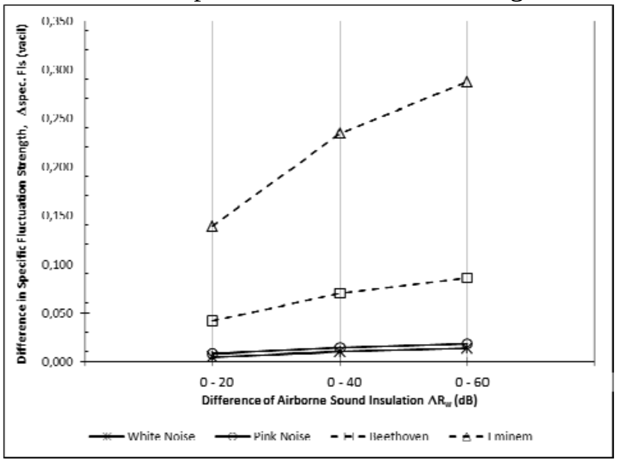

Figure 11. Difference in specific fluctuation strength (Δspec. Fls) as a function of the difference in airborne sound insulation (ΔR) for different source signals. All source signals have a SPL of 85 dB.

It is seen from Figure 11 that for noise type signals the change in fluctuation strength is little but for music type signals the change is very clear. It is observed that although the difference in sound insulation is constant the change in fluctuation is not. “Eminem” and “Beethoven” drop in fluctuation after the first transmission from the source signal to the transmitted signal by about 40% and then by about 44%. This means that the specific fluctuation strength decreases by increasing airborne sound insulation. Increasing the sound insulation by about 20 dB decreases the specific fluctuation strength by about 40%. It is notable that this holds for any of the investigated steps. This means that the reduction in fluctuation strength is roughly independent of the starting point of the airborne sound insulation as long as the improvement of sound insulation is equal. It is noted that noise type source signals (pink or white noise) do not change much in specific fluctuation strength with increasing sound insulation, which is expected, but this could be an indication that transient signals, i.e. non-steady-state signals, can be more influenced with appropriate sound insulation in the sense of subjective judgments to rate the annoyance of the receiving sound between a dividing partition.

6. Summary

The airborne sound insulation as currently used in the actual European Standards is not well related to the psychoacoustic facts to describe sensation. The judgment of a sound signal which was transmitted through a dividing partition is supposed to be a measure of the quality of the airborne sound insulation. This preliminary investigation shows that the receiving sound signal is depending on the unfiltered source signal and not only on the value of the airborne sound insulation. This result implies that using pink noise as a test signal in order to measure sound insulation does not relate well with hearing sensation. It has also been shown in this research, that using psychoacoustic measures separately as a measure to describe the intrusive sound does not describe the subjectively estimated impression properly. This can be seen, for example, for the sensation roughness, which is not applicable in all cases, especially at high values of sound insulation. Instead of the psychoacoustic measure roughness the specific fluctuation strength yields results which are non zero and is hence prefered. Comparison of specific fluctuation strength clearly showed that airborne sound insulation is depending on the source signal and its spectral and temporal characteristics. Overall, it is seen that the time structure of signals plays a very important role in rating the sound.

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