The influence of the reproduction system on the results of the listening tests in building acoustics

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Summary

The way humans perceive sound has become an important factor in building acoustics, thus opening a path to subjective evaluation of sound insulation properties of building elements through listening tests. Different approaches have been taken in order to present the sound stimuli to listeners in the most realistic way possible.

The reproduction of sound stimuli during listening tests related to building acoustics is usually carried out over headphones, being a very convenient way for the reproduction of acoustic stimuli in general. Nevertheless, in some cases a realistic reproduction over headphones is impossible. On the other hand, loudspeaker systems allow the subject to perceive the sound in a more natural way, related first and foremost to source localization. However, the use of a loudspeaker system implies the interaction of the system with the listening room; a problem that can be minimized provided that the listening room has been properly treated in the acoustic sense.

To examine the influence the sound reproduction system itself has on the results of the listening tests carried out in building acoustics, a listening test was designed and executed with the stimuli reproduced over two different reproduction systems. The same sound stimuli was reproduced once over the headphones, and in the second experiment a stereo listening setup made of two bookshelf-size studio monitor loudspeakers aided by a subwoofer was used. The listening test itself was designed to assess the quality of airborne sound insulation of different building elements through loudness judgements. Namely, the test compared the sound insulation properties of a typical lightweight and massive inner wall, as well as a typical outer wall with and without an ETICS façade (external thermal insulation composite system). Pink noise, music and traffic noise were filtered using the sound reduction index vs. frequency curve, and then used as the stimuli in the experiment.

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1. Introduction

Over the past several decades, different approaches have been developed towards the objective evaluation of sound insulation properties of building elements in the form of single-number parameters. These parameters are derived from laboratory and in-situ measurements. To take into account the way humans perceive sounds, basic psychoacoustic concepts have been incorporated into the evaluation process. [1, 2, 3, 4]

Evaluation of sound insulation properties of building elements in a truly subjective manner, i.e. through listening tests, is a new concept in the field of building acoustics. With the development of new building techniques, it has become clear that the differences between various building constructions regarding their sound insulation properties cannot be described using only single-number parameters obtained from objective evaluation. In other words, the single-number values do not necessarily reflect how people will perceive the quality of sound insulation of a given wall or ceiling, especially when it comes to comparing different massive and lightweight constructions. Therefore, efforts have been made to improve the methods of calculating the single-number parameters by improving the psychoacoustic concepts built into those methods. The data necessary for making these improvements has been obtained from listening tests as a principal tool for subjective evaluation.

To use standardized listening tests in subjective evaluation, a methodology is required for their design and execution. One of the problems in listening tests is how to present the sound stimuli to the listener. The sound reproduction system used for this purpose is usually chosen based on financial availability, while its technical features and the resulting advantages and disadvantages are often ignored.

The argument made here is that the sound reproduction system should be regarded as an important variable that can have a significant influence on the results of listening tests and the entire subjective evaluation process, rather than just a tool used for reproducing sound stimuli. The main question to be answered is the difference between reproduction over headphones and over loudspeaker-based systems, with the emphasis on spatial audio reproduction systems such as Ambisonics.

Subjective evaluation is carried out in laboratory conditions, based on sound scenarios obtained through auralisation, with the goal of (re)creating real or simulated sound environments. Achieving accurate reproduction is crucial. In subjective evaluation in the field of building acoustics, the principal task of the sound reproduction system is to maintain the correct direction of arrival of reproduced sounds, thus making it possible to recreate the scenarios of sound coming from different directions and locations. The frequency content of reproduced sounds should be as accurate as possible, if the sound insulation of the investigated building elements is to be presented properly.

This paper presents the results of the first experiments made to examine the influence the sound reproduction system itself has on the results of listening tests carried out in building acoustics. Specifically, a listening test was made in which the same sound stimuli was reproduced over headphones, and using a loudspeaker stereo listening setup. The experiment was designed to evaluate the quality of airborne sound insulation of different building elements through loudness judgements.

2. Experimental setup

Stimuli and scenarios

The stimuli used in the listening tests was created by filtering various source sounds. The chosen source sounds are pink noise, a sample of popular music with pronounced low-frequency content, and a sample of noise produced by a gasoline engine idling at 2000 rpm. The length of the sounds were around five seconds and the required filters were defined to represent the frequency-dependent attenuation that would happen when sound would propagate through a building element. Four filters were defined altogether. Two of them represent the typical massive and the typical lightweight party wall, while the remaining two represent a massive outer wall of a building with and without an ETICS façade. The pink noise and the music sample were filtered to simulate their propagation through the lightweight and the massive party wall. The sample of engine sound was filtered to simulate its propagation through the outer wall with and without ETICS façade. All the filtering was done in MATLAB. The frequency range was set to 20-6300 Hz, so that the lowest audible frequencies are included as well.

Listeners

A total of 63 listeners took part in these experiments, with their age ranging from 19 to 55, with the average age of 25. Unfortunately not everyone was able to do all tests with different reproduction systems, so per analysed group 17 to 24 subject results existed. Out of them, 4 were female, and 59 were male. Altogether, just one of them reported some kind of hearing impairment they were aware of at the time of the test. No reward was offered or given for participation in the listening tests.

Procedure

All tests were performed in the Psychoacoustic Laboratory at TGM in Vienna, equipped with a headphone-based listening unit, as well as a multichannel loudspeaker system. The laboratory is acoustically treated, and steps were taken to insulate it from the rest of the building as much as possible.
The light in the laboratory was kept at a low level to reduce the influence of the laboratory environment on the listeners, but still high enough for the listeners to feel pleasant.
The experiments were done using two different sound reproduction systems. Firstly, reproduction over headphones was utilized using a pair of open circum-aural headphones, namely, the Sennheiser HD 650. The same experiments were then repeated using a pair of small, bookshelf-size active studio monitors, namely, the Neumann KH 120, aided by two subwoofers Eve Audio TS 110.
The listening test itself was implemented in Microsoft Excel using Visual Basic for Application. The listener controlled the listening test over a tablet which was used as a remote control for the computer system. The details on the operation of the test can be found in [5]. Besides collecting the data about the listener, as shown in Figure 1, the application also exports the results and makes various kinds of analyses once the test has been completed by a large enough group of listeners. The interface used in testing is shown in Figure 2.

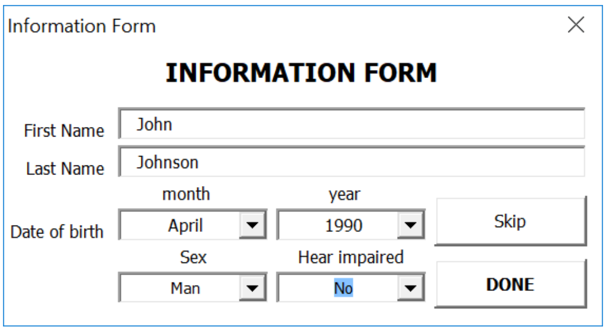


Figure 1. The GUI used for collecting the basic information about the listener

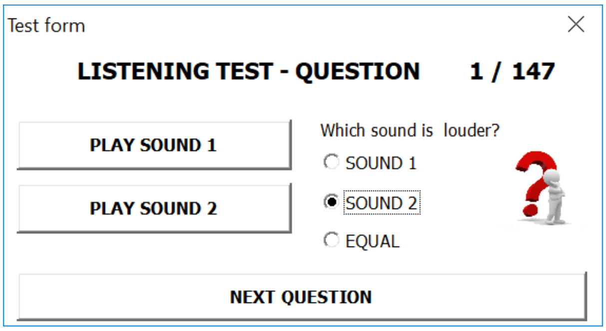


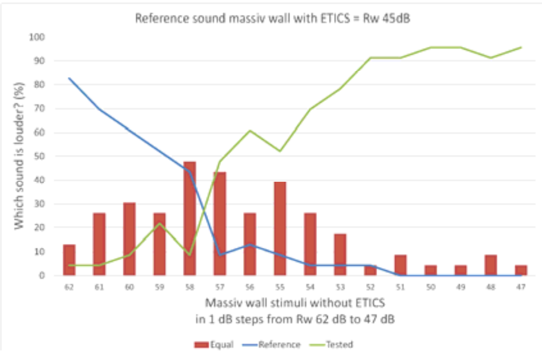
Figure 2. The GUI of the listening test

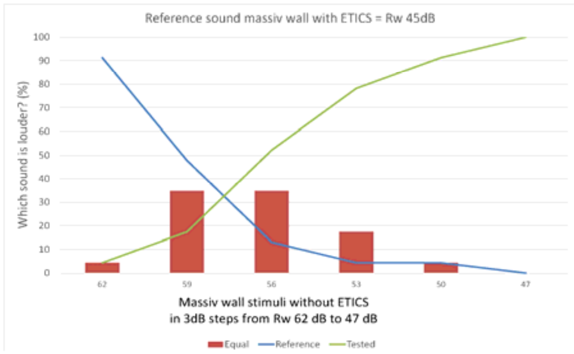
The sounds are presented in pairs, randomly, with the intent of making a direct comparison of their perceived loudness. The pairs are formed out of two filtered sounds that originate from the same source sound. The goal is to investigate the difference between the lightweight and the massive party wall, and the difference between the massive outer wall with and without an ETICS façade.
One of the sounds is declared the reference sound, and its level is kept constant. The other sound in the pair is declared as the tested sound, and its level is varied. Two cases were investigated: a coarse level variation in steps of 3 dB, and a fine level variation in steps of 1 dB. In this particular case, the sound coming through the lightweight wall is the reference sound, whereas the sound coming through the massive wall is the tested sound. Similarly, the sound coming through an outer wall equipped with an ETICS façade is the reference sound, while the sound coming through an outer wall with no such façade is the tested sound.
The task given to the listeners was simply to evaluate the loudness of both sounds in each pair and to decide which sound is the louder one, or to judge them both as equally loud.

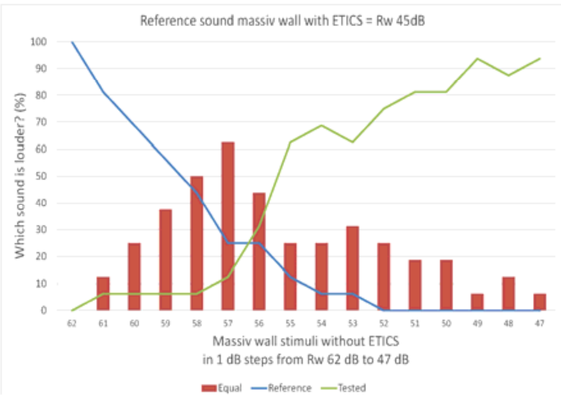
3. Results and discussion

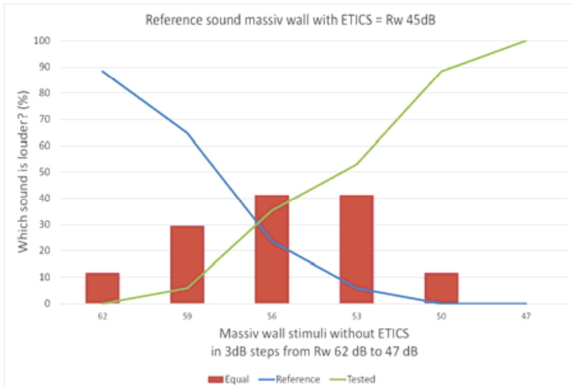
The responses of subjects were analysed statistically, on the judgment of stimuli pairs as equal, but also based on percentage of rated sound stimuli as louder. The results of the analysis were divided in two different reproduction systems and three different stimuli sounds. (See Figure 3 to 5)
The analysis shows that just pink noise, as a sound stimulus, was perceived on both reproduction systems very similar.
A shifting on the perception of loudness on different reproduction systems could be seen on typical neighbour sound. These particular stimuli were simulating music, coming from a neighbour,

or sound of a car engine, coming through an outside wall.
The following figures (Figure 3 to 5) show the rating of equal soundpairs is shifting between headphones and loudspeakers. The sound stimuli which simulate real neighbourhood sound, like music or car engine, seem to be perceived by the probands on loudspeaker as louder. So the equal loudness perseption is shifting towards a higher insulation. In case of pink noise stimuli, the test results are different. The most equal stimuli pair are on headphones and loudspeakers the same, but if you compare the pink noise results in 1 dB steps, wich sound is louder rating is shifted towards a lower insulation on loudspeakers.

<table>
<tr><td>Massiv wall with ETICS R_w 45 dB compared with massiv walls, car engine stimuli in 1 dB steps</td><td>Massiv wall with ETICS R_w 45 dB compared with massiv walls, car engine stimuli in 3 dB steps</td></tr>
<tr><td>

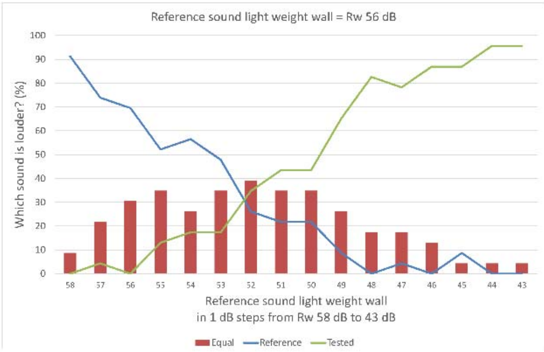
Test on loudspeakers</td><td>

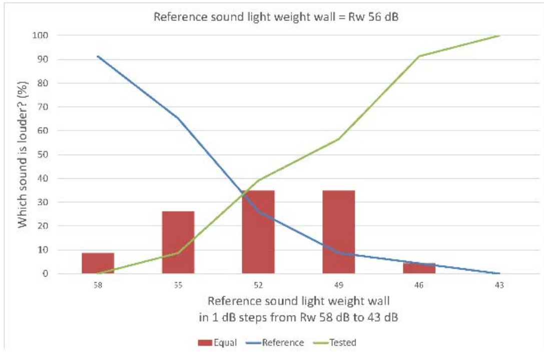
Test on loudspeakers</td></tr>
<tr><td>

Test on headphones</td><td>

Test on headphones</td></tr>
</table>

Figure 3. Shows the results of car engine sound through a massiv wall with ETICS compared with massiv walls without ETICS.

<table>
<tr><td>Lightweight wall with R_w 56 dB compared with massiv walls without ETICS; music stimuli in 1 dB steps</td><td>Lightweight wall with R_w 56 dB compared with massiv walsl without ETICS, music stimuli in 3 dB steps</td></tr>
<tr><td>

Test on loudspeakers</td><td>

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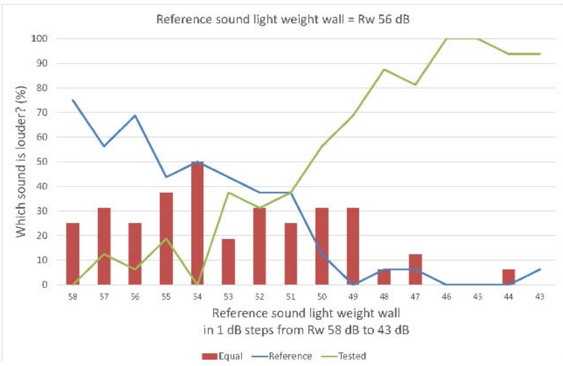
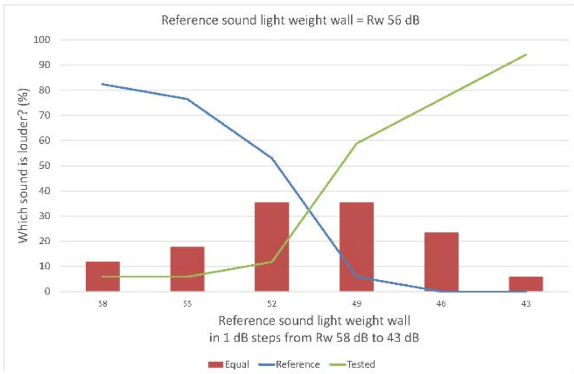
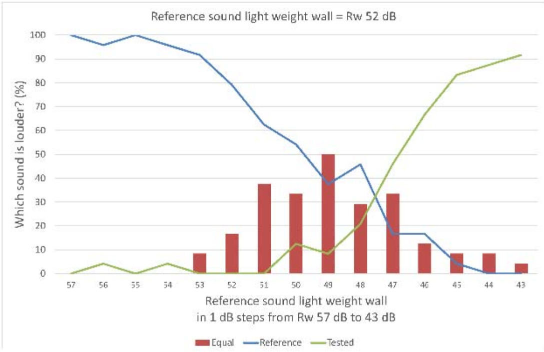
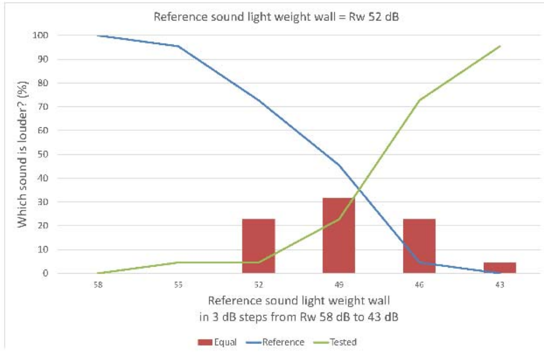
<tr><td>

Test on headphones</td><td>

Test on headphones</td></tr>
</table>

Figure 4. Shows the results of music stimuli through a lightweight wall compared with massiv walls without ETICS.

<table>
<tr><td>Lightweight wall with R_w 52 dB compared with massiv walls without ETICS, pink noise stimuli in 1 dB steps</td><td>Lightweight wall with R_w 52 dB compared with massiv walls without ETICS, pink noise stimuli in 3 dB steps</td></tr>
<tr><td>


Test on loudspeakers
</td><td>


Test on loudspeakers
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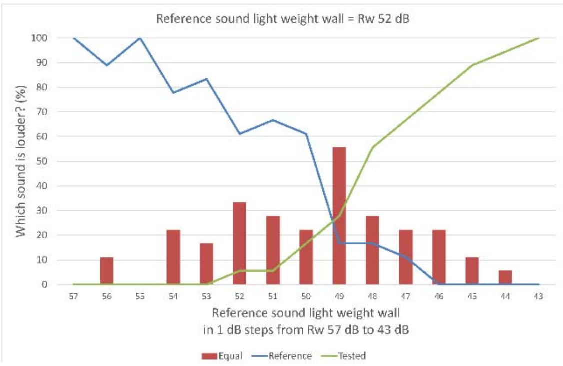
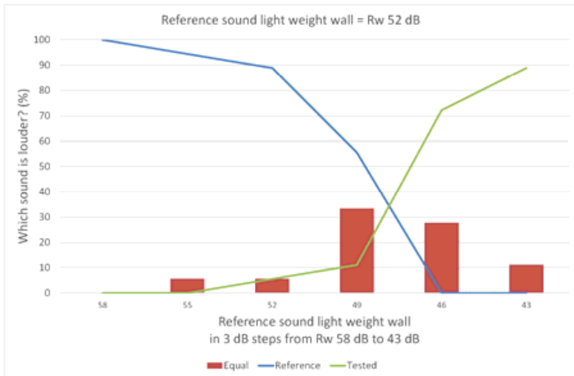


Test on headphones
</td><td>


Test on headphones
</td></tr>
</table>

Figure 5. Shows the results of pink noise stimuli through a lightweight walls compared with massiv walls without ETICS.

4. Conclusions

Listening test will be continued with more subjects, with a better gender balance, and could be expanded with an additional setup using headphones and subwoofer boxes simultaneously, to investigate the importance of impact noise or vibrations on human perception on listening test stimuli in building acoustics. Another expansion of the test should include more different urban sound stimuli. The calibration of the two reproduction systems was done with an artificial ear for headphones and a free field microphone for the loudspeakers. A calibration with the same system, e.g. a dummy head, could help to compare the frequency response of the headphones and the speaker system to optimize the testing setup in the acoustic labratory.

Acknowledgement

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References

[1] Scholl, W., Lang, J., & Wittstockh, V. (2011). Rating of sound insulation at present and in future. The revision of ISO 717. *Acta acustica united with acustica*, *97*(4), 686-698.

[2] Virjonen, P. K., & Oliva, D. (2016, August). Optimized reference spectrum for rating airborne sound insulation in buildings against neighbor sounds. In INTER-NOISE and NOISE-CON Congress and Conference

Proceedings (Vol. 253, No. 1, pp. 6910-6915). Institute of Noise Control Engineering.

[3] Hongisto, V., Oliva, D., & Keränen, J. (2014). Subjective and objective rating of airborne sound insulation–living sounds. Acta Acustica united with Acustica, 100(5), 848-863.

[4] Ljunggren, F., & Simmons, C. (2018). Airborne sound insulation between dwellings, from 50 vs. 100 Hz–A compilation of Swedish field surveys. Applied Acoustics, 133, 58-63.

[5] Zelem L., Technical challenges in preparation of listening tests, Proceedings of ATF 2017, 280-292