ANALYSIS OF NEIGHBOURING NOISE DISTURBANCE IN RECEIVING ROOM

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ABSTRACT

This paper is focused on analysis of neighboring noise as a disturbance agent. This problematics is closely connected with psychoacoustics or more generally with psychology. Therefore, methodology of research is based primarily on listening tests and questionnaires. The main research question lies in evaluation of difference of low/medium/high pitch noise on acoustic comfort of users. For purpose of this a method of auralization was introduced. The model was created by ODEON software and source noises were virtually reproduced through different partition walls. The virtual records in receiving room were accordingly replayed within listening tests. Results have shown that it is not easy to define one exact formula and answers depend on exact sounds and even there is not agreement through all of respondents. It should be mentioned that amount of respondents is too small for any definite statements. However, there is non-obvious and unexpected inclination to evaluated multi-layered light-weight structures as subjectively worse than adequately insulating concrete wall – at least from results obtained in this test. The possible explanation is an unnatural frequency spectrum of resulting sounds which are perceived as more disturbing despite they have lower sound pressure levels then in case of structure from reinforced concrete.

KEYWORDS

Listening tests, auralization, frequency, sound reduction index, subjective evaluation

INTRODUCTION

An impact of sound waves to humans is possible to display by physical quantities and their dependence. It is primarily sound pressure level L (dB) and frequency f (Hz) or frequency spectrum of sound. In case of enclosed space e.g. rooms there are more quantities. As an example there can be described Reverberation time T (s), coefficient of absorption α (-), different echoes descriptors and many others. If the source of sound is in different room it is also necessary to take into account the sound level difference D (dB) or another quantity which describes insulation such as sound reduction index R (dB). Despite great approximation we have at least 5 the most essential variables which the subjective evaluation of noise disturbance depends on.

The second option is using of modern method of auralization and to model surroundings which properly respond to real conditions which we want to describe. Then to take this model and inside it we can numerically process a sound signal of the source and get the sound signal in the receiving room after transferring through the partition element. The final signal is after that introduced into listening tests and statistically analyzed. The latter option which is based on psychoacoustic is discussed in this paper.

Nowadays there is a great effort to draw auralization and human perception in general to the sound insulation problems directly – without excessive amount of hard data. One example, which is commercially used is dB station [3]. It is a graphic user interface, which allows user to change both insulations between him and a source and a source of disturbing noise itself.

A goal of this work is neither to embrace all problematic of transmission of sound energy nor to bring a clear and an undiscussable solution how to eliminate low frequency sound propagating through structure elements. This work intends to point out second option for evaluation of sound insulation. The goal depends on creating methodology and process, which can lead to providing reliable and correct data. This system can be used later for bigger investigation about respondents, spatial geometry, different source signals and different partitions. The work is focused on environments in residential building and neighboring noise and only with perspective of airborne sound. That is a reason for choice of source sounds, localization of sources and receivers in rooms, dimensions and acoustic properties of rooms and choice of partitions. Next limitation is that only heathy people without hearing losses are involved into this research.

METHODS

This section describes in detail the study material, procedures and methods, which were used for this work. It is divided into a few subsections about software model, sources of sound, partitions, listening test and post processing of questionnaires.

Software model

The model was created in ODEON[6] software (version 10.1 Combined – suitable for educational and research purpose only) which is the software specialized for room acoustic simulation and measurements and is recently used also for auralization. This exact feature was used in this project. The model itself consists of two adjacent rooms, which have the dimensions and shape of acoustic laboratory at UCEEB where the verification process of model was held.

Sources

Five different sources of sound were implemented into the model. Choice of sources was done due to intention of covering commonly occurred sound in neighboring conditions. All of five source signals are displayed bellow:

Music – Daft Punk - Get Lucky

Music – Beethoven - Für Elise

Barking of a dog

Crying baby

Sports event

All the sounds were reproduced by high-quality loudspeaker Nor276, except second sample – Beethoven was played by electric piano right in the source room of the acoustic laboratory.

Structures

For samples of partitions there were used three kinds of walls commonly used in buildings. All of them had the same sound reduction index *Rw = 64 dB.* The effect of bypassing sound is eliminated by laboratory and also by computer model.

1. Concrete wall (area density m' = 600 kg/m^2)
2. Plasterboard wall (area density m' = 45 kg/m^2)
3. Aerated wall with lining (area density m' = 118 kg/m^2)

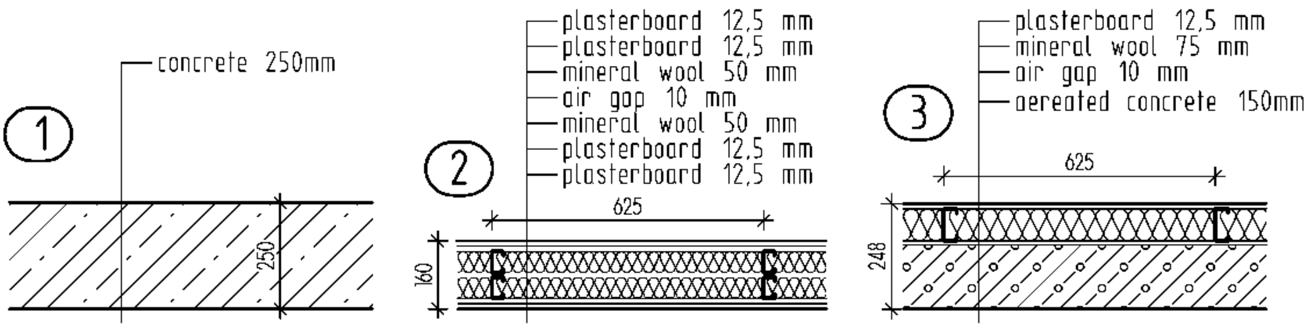

Fig. 1: Three tested structures

The sound reduction index for each of those partitions is displayed in Chart 1. There is a clearly visible difference between them and critical frequency of multi-layered structures. The values of sound reduction index of structures were measured in the acoustic laboratory.

Frequency	R [dB] (1/3 octave bands)			
[Hz]	concrete	plasterboard	aerated c.	ISO 717
50 Hz	40,0	17,6	28,4	
63 Hz	42,1	20,8	26,3	
80 Hz	40,8	30,3	32,6	
100 Hz	43,2	35,1	40,9	41
125 Hz	45,7	39,9	44,4	44
160 Hz	48,4	45,3	47,4	47
200 Hz	50,8	50,3	50,9	50
250 Hz	53,3	55,4	51,1	53
315 Hz	55,8	60,6	53,4	56
400 Hz	58,5	66,1	60,0	59
500 Hz	60,9	66,9	66,1	60
630 Hz	63,5	70,1	72,4	61
800 Hz	66,1	73,2	73,9	62
1000 Hz	68,6	75,7	76,9	63
1250 Hz	71,5	77,4	79,6	64
1600 Hz	73,2	80,5	83,2	64
2000 Hz	74,8	79,8	84,6	64
2500 Hz	76,3	72,2	82,6	64
3150 Hz	77,9	77,9	87,4	64
4000 Hz	79,6	84,3	92,6	
5000 Hz	81,2	90,3	97,5	

R_w (dB)	64	64	64
C (dB)	-1	-4	-2
C_{tr} (dB)	-6	-11	-7

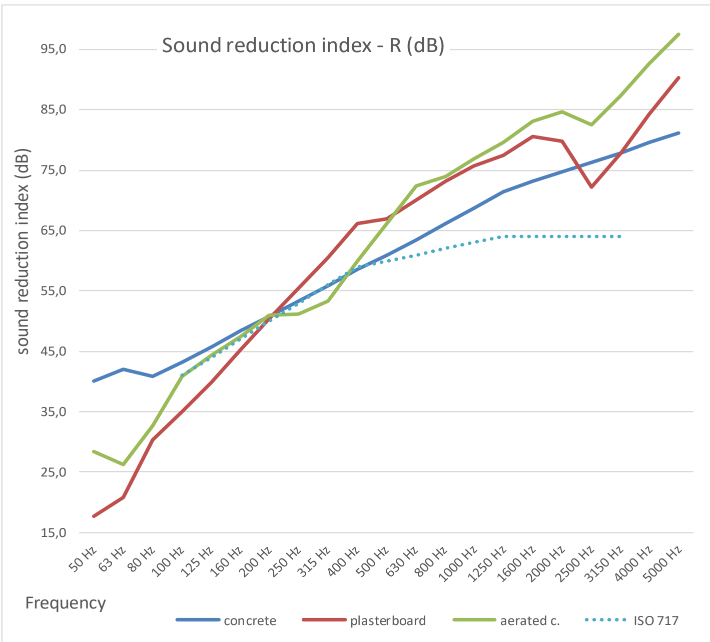

Chart 1: sound reduction indexes of partitions

Auralization

Auralization technique was used to obtain sound records in receiving room. The philosophy of auralization is a creating audible sound files from numerical (simulated, measured or synthesized) data [5]. These records were afterwards implemented into listening tests. Except of using different partitions and source sounds all properties of model remain the same in all cases.

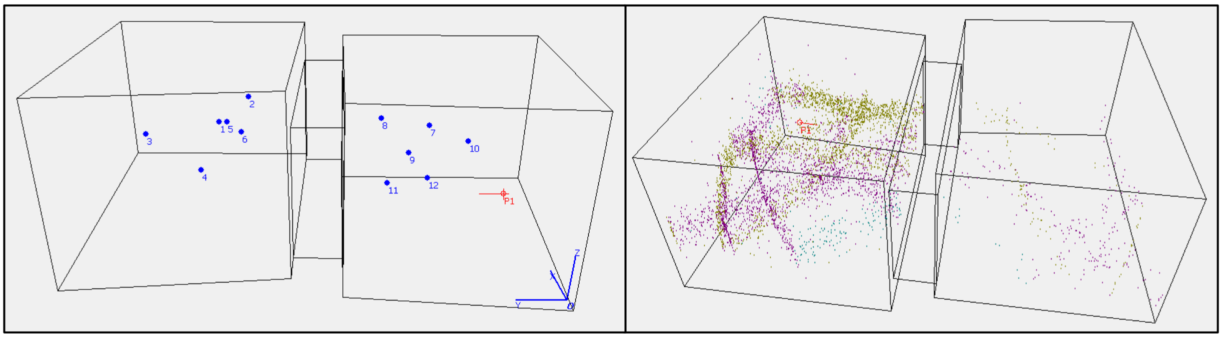

Fig. 2: A picture of model in ODEON software.

Verification of this software model was done by a comparison of records obtained by auralization and records which were physically recorded in receiving room during measurements. These measurements were realized at university center for energy efficient buildings (UCEEB) in Buštěhrad. More about the verification of this model is available in conference contribution [2]. In this model there is only one direct acoustic path.

Listening test

There was a simple examination of respondents before listening test itself. The examination was held in order to reveal any cruel pathology of respondents by a free online audiology test [1]. The online test was firstly tested by a comparison with my audiogram from a doctor. Results of the comparison were sufficient for purpose of this test because it was not important to know exact threshold of hearing but to know if hearing spectrum is more or less flat and without any significant hearing spans in any frequency (according to A weighting).

Every tested respondent was questioned about his acoustic background, sex, age, and preferable acoustic comfort at the beginning of the test in a graphic user interface (GUI). All questionnaires were anonymous and done with supervision of test manager or his representative. The respondents were chosen semi-randomly and fully voluntarily. There was also retained ethic codex of listening tests with requirements to health and comfort of respondents.

For listening, there was used a headphone set SEP 629 with this technical parameter specification:

Diameter of loudspeaker: Ø 40 mm

Impedance: 32 Ω +/- 10 %

Frequency span: 20 Hz - 20 kHz

Sensitivity: 106 dB +/- 3 dB /1 mW (SPL at 1 kHz)

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The first page of GUI was intending to acquire information about respondent's background and living conditions as well as gender and age. The evaluation scale for this purpose was from 1 to 5 (1… I totally agree with the statement; 5… I totally disagree with the statement). Questions about background were (in this order):

I feel sensitive to surroundings sounds.
I intentionally avoid events with excessive sound (party, sports events).
I wake up during night because of noise; I usually notice disturbing sound later than others.
When in loud surroundings I focus better than my colleagues.
I prefer weekends and relax in a quiet place.

Listening test consists of evaluation sets of three sounds which had the same sound in the source room however sound in receiving room (which were recorded) differ due to fact that different partition was used. There were five of these sets – every set for one source sound. Altogether 15 (3x5) sounds were evaluated. For purpose of evaluation there was progress bar from 1 to 10 – from minimal disturbance or loudness to maximal disturbance or loudness. This method is called interval scale valuation. The benefit of this method lies in easier further analysis of answers – at least in comparison with nominal evaluation which is based on verbal description by the respondents [4]. Average length of one listening test – including introduction and feedback - was 15 minutes.

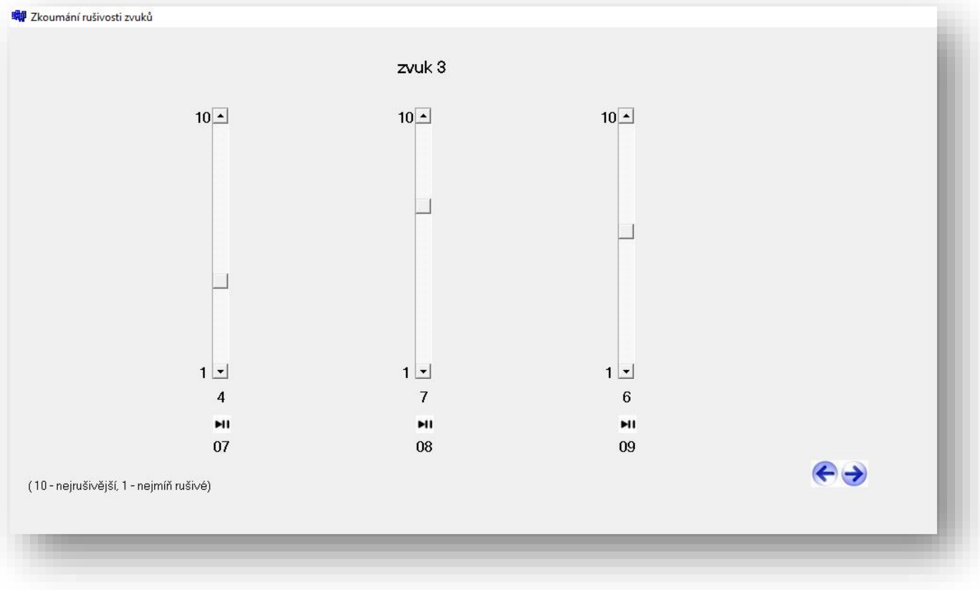

Fig. 3: A sample of screen in questionnaire.

In Figure 3, there is a sample of screen from questionnaire, which shows user interface. This respondent has a task to evaluate subjective disturbance in three samples. The primary sound is sound 3: barking of a dog. However in the first column there is a scale for sound which is going seemingly through structure 1 (Concrete wall), in second column through the structure 2 etc.

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Processing of questionnaires

The amount of finished listening tests was 28. The selection of population was semi-random, based on voluntarily enlisting for testing. However, a few questionnaires were r removed from analysis. There were several reasons for doing this. The most often problem was hearing loss or another physiological hearing defect. Five respondents did not pass through this criterion. And two other respondents showed irresponsible attitude and their results were also not taken in analysis.

Answers from questionnaires were processed by commonly used statistical methods. Neither concordance nor consistence were evaluated due to too low number of respondents and in perspective of lack of further work with this population.

Expected results were significantly higher numbers (the more loudness) for low frequency sounds (first and second sample) in structure number two and three. However, for higher frequency sounds (third and fourth sample) in structures number one. This presumption has not been fulfilled in the scale, which could be expected. No significant difference was found between answers from male and female part of population. In addition, no significant correlation was found between responses and background of respondents or their age. The complete set of answers, which was processed, is in table below (Table 1). In the column “living”, there are a few possibilities: ST – small town. BG – big town, R - rural area. Numbers in table represent answers of respondents to questionnaire. First part contents responses to background questions (see chap. Listening tests), second part contents exact location of progress bar on “disturbance scale” for each sound file.

Tab. 1: whole population, their background and answers

sex	age	living	background						sounds														
			1	2	3	4	5	6	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
F	78	ST	4	2	5	2	5	2	1	3	2	1	2	2	6	7	5	3	4	3	8	9	6
F	76	ST	2	2	5	5	1	2	2	3	1	1	1	1	3	3	4	2	2	4	3	3	3
F	73	ST	1	1	5	1	5	1	2	2	2	2	3	1	2	3	5	1	2	4	3	4	5
M	40	BG	1	1	3	1	4	1	3	4	2	2	2	1	7	7	8	3	2	3	8	9	5
F	44	ST	2	3	5	5	5	3	1	1	1	2	3	1	5	6	3	8	10	7	10	10	6
F	48	ST	1	1	1	1	5	1	3	4	1	1	1	3	10	10	5	6	8	10	3	5	8
F	42	ST	3	1	4	2	5	1	4	6	1	1	1	4	8	7	4	6	6	8	9	10	7
F	53	R	1	1	5	3	5	1	2	3	1	1	1	1	3	3	3	1	1	2	5	7	7
F	50	ST	1	1	1	5	3	1	5	6	4	2	2	1	3	5	6	5	5	7	7	9	7
F	41	ST	1	1	1	5	5	1	1	1	1	1	1	1	1	1	1	1	1	1	3	10	4
M	11	ST	2	4	2	2	3	2	1	2	1	3	3	1	5	4	1	4	3	2	6	4	1
F	12	ST	3	1	5	1	3	2	8	9	1	2	3	1	8	9	10	6	8	10	7	5	8
M	9	ST	2	1	2	1	5	3	5	2	1	1	1	1	2	3	1	1	1	2	1	1	1
M	13	ST	3	4	4	5	5	4	5	4	2	2	2	1	3	3	3	4	4	6	3	2	4
F	45	ST	2	1	4	1	5	1	2	4	1	2	2	1	6	6	8	8	5	8	8	9	8
M	39	ST	4	2	3	1	5	3	2	3	1	1	1	1	5	7	8	3	5	9	9	9	5
M	6	ST	2	1	4	4	3	3	2	2	1	1	1	1	1	1	3	9	9	10	1	2	4
M	25	ST	3	1	5	2	3	1	3	4	1	1	1	1	3	3	2	5	7	4	7	10	2
F	26	ST	2	2	5	3	5	1	5	8	2	3	7	1	3	5	5	2	7	5	5	8	2
F	54	ST	3	1	2	3	5	1	2	3	2	2	2	1	2	3	3	4	4	7	2	3	4
M	56	ST	2	1	3	1	3	1	7	8	1	1	1	1	7	7	6	6	7	5	9	10	4

Due to need of comparison within each set separately there is an appropriate method to establish one reference level. In this case the concrete wall was considered as a reference level and then compared to the other structures for percentage display. Evaluating within each set has the advantage that it is not necessary to deal with concrete set up volume in case of reproduction of noise through loudspeakers and it is possible to deal with problematic in more general way.

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Tab. 2: results in percentages with reference of concrete wall

respondent	sounds - percentage with reference of reinforced concrete									
	2	3	5	6	8	9	11	12	14	15
1	300%	200%	200%	200%	117%	83%	133%	100%	113%	75%
2	150%	50%	100%	100%	100%	133%	100%	200%	100%	100%
3	100%	100%	150%	50%	150%	250%	200%	400%	133%	167%
4	133%	67%	100%	50%	100%	114%	67%	100%	113%	63%
5	100%	100%	150%	50%	120%	60%	125%	88%	100%	60%
6	133%	33%	100%	300%	100%	50%	133%	167%	167%	267%
7	150%	25%	100%	400%	88%	50%	100%	133%	111%	78%
8	150%	50%	100%	100%	100%	100%	100%	200%	140%	140%
9	120%	80%	100%	50%	167%	200%	100%	140%	129%	100%
10	100%	100%	100%	100%	100%	100%	100%	100%	333%	133%
11	200%	100%	100%	33%	80%	20%	75%	50%	67%	17%
12	113%	13%	150%	50%	113%	125%	133%	167%	71%	114%
13	40%	20%	100%	100%	150%	50%	100%	200%	100%	100%
14	80%	40%	100%	50%	100%	100%	100%	150%	67%	133%
15	200%	50%	100%	50%	100%	133%	63%	100%	113%	100%
16	150%	50%	100%	100%	140%	160%	167%	300%	100%	56%
17	100%	50%	100%	100%	100%	300%	100%	111%	200%	400%
18	133%	33%	100%	100%	100%	67%	140%	80%	143%	29%
19	160%	40%	233%	33%	167%	167%	350%	250%	160%	40%
20	150%	100%	100%	50%	150%	150%	100%	175%	150%	200%
21	114%	14%	100%	100%	100%	86%	117%	83%	111%	44%
median	133%	50%	100%	100%	100%	100%	100%	140%	113%	100%
average	137%	63%	118%	103%	116%	119%	124%	157%	129%	115%
variance	0,264	0,180	0,135	0,803	0,066	0,455	0,352	0,656	0,314	0,745
standart deviation	0,514	0,424	0,367	0,896	0,257	0,675	0,593	0,810	0,560	0,863

RESULTS

Result table shows that the answers do not incline to uniform direction. The scale of evaluation is very wide and each respondent has his own perception and therefore different feeling about the sound. However, it is possible to say that acoustic behavior of lightweight multi-layered partitions is more difficult and problematic than concrete structure (it would have 100% in table as a reference sample).

The table is colored according relative answers of respondents. A lot of cells remain yellow which means that the difference from the reference sound is not perceived or is very small, green cells indicated that the sound is perceived as less loud and on the opposite side - red cells indicates that the sound is perceived as louder than reference sound.

Below the table there are simple statistical tools as median, average, variance and standard deviation of the population.

It is very interesting that respondents do not have the same opinion on sounds and therefore the scale is enormous – as an example we can take the sound 6 – piano through aerated concrete wall with lining. There is value span from 33% up to 400% - it can be because of a personal exception but it only shows that this problematics is very complex and numerous variables are involved in it.

CONCLUSION

This research is done on a relatively small amount of respondents and therefore the results should be considered only as an overview. For exact output and implementation there will be necessary to perform more tests similar to this one. Nevertheless, this work proved that it is essential to focus on comparison between the multi-layered and the single-layered structures from perspective of sound insulation. There is a question what quantity describes the best the sound insulation performance. In this case the sound reduction index R_w was used in spectrum from 100 to 3150 Hz, maybe a spectrum adaptation term should be added – such as *C* or C_{tr} in case of façade and traffic noise.

Next research should provide deeper insight into this problematics of evaluation of sound insulation from user's point of view. This paper provides basic concept of possible test, but in very limited scale. Only five evaluated sounds and three partitions were covered and only 21 sets of answers were taken into account and subjected to further analyze. The exact form of listening tests which were presented showed its relevance and feasibility and that was the main aim and contribution of this research.

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